9-2022

Maxillary Central Incisor RR in Hispanic and Non-Hispanic White Patients with RME

Madison Healy

LOMA LINDA UNIVERSITY
School of Dentistry
in conjunction with the
Faculty of Graduate Studies

Maxillary Central Incisor RR in Hispanic and Non-Hispanic White Patients with RME

by

Madison Healy

A thesis submitted in partial satisfaction of
the requirements for the degree
Master of Science in Orthodontics and Dentofacial Orthopedics

September 2022

Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

, Chairperson

V. Leroy Leggitt, Professor of Orthodontics and Dentofacial Orthopedics

Gabriela Garcia, Assistant Professor of Orthodontics and Dentofacial Orthopedics

Kitichai Rungcharassaeng, Professor of Orthodontics and Dentofacial Orthopedics

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude and appreciation for all those who helped me complete my thesis. I would like to sincerely thank my committee members, Dr. Leggitt, Dr. Kit and Dr. Garcia, for their help and guidance throughout the course of my project. I'd also like to thank Mike, Jasmine, and the rest of my family for their never-ending support and for always believing in me.

CONTENT

FIGURES

TABLES

ABBREVIATIONS

T1	Pre-Treatment
T2	Post-Treatment
3D	Three-Dimensional
LLU	Loma Linda University
RME	Rapid Maxillary Expansion
EARR	External Apical Root Resorption
RR	Root Resorption
CBCT	Computed Cone Beam Tomography
DICOM	Digital Imaging and Communications in Medicine
MPR	Multi-planar Reconstruction View
ANCOVA	Analysis of Covariance

ABSTRACT OF THE THESIS

Maxillary Central Incisor RR in
Hispanic and Non-Hispanic White Patients with RME

by

Madison Healy

Master of Science in Orthodontics and Dentofacial Orthopedics
Loma Linda University, September 2022
Dr. V. Leroy Leggitt, Chairperson

Introduction: Apical root resorption is one of the most common adverse effects of orthodontic treatment. Forces used during orthodontic tooth movement can cause permanent loss of apical surfaces of teeth and although most reported cases of root resorption are asymptomatic, the process is irreversible and often unpredictable. Thus, it is of clinical interest to investigate which patients may be at greatest risk.

Purpose: This study utilized Cone Beam Computed Tomography (CBCT) to evaluate whether rapid maxillary expansion (RME) in Hispanic patients increased the severity of orthodontically induced apical root resorption.

Materials and Methods: Pre-treatment (T1) and post-treatment (T2) Digital Imaging and Communications in Medicine (DICOM) CBCT images of patients treated at Loma Linda University were imported into OsiriX MD software (version 12.5.2, Pimeo, Bemex Switzerland) for tooth length measurement of maxillary central incisors in sagittal and coronal views. The amounts of root resorption (RR) were calculated and compared between Hispanic and Non-Hispanic White patients treated with and without RME using analysis of covariance (ANCOVA). Spearman Rho correlation tests and Chi-squared analysis were performed to evaluate the relationship between RR and age, gender, and treatment time. All statistical analyses were performed at $\alpha = 0.05$.

Results: A total of 180 patients were included in this study. Non-Hispanic White patients that underwent rapid maxillary expansion experienced greater amounts of root resorption ($p > .05$) compared to Hispanic and non-expansion patients. There were no statistically significant differences in overall RR comparing expansion and non-expansion groups, or between ethnicities ($p > .05$). Age, treatment time, and gender showed no statistically significant correlation with RR ($p > .05$).

Conclusions: Non-Hispanic White patients that underwent rapid maxillary expansion experienced statistically, but not clinically, significant higher levels of root resorption. Age, treatment time and gender had no effect on RR.

CHAPTER ONE

REVIEW OF THE LITERATURE

External apical root resorption is one of the most common iatrogenic consequences of orthodontic treatment.[1] This undesirable outcome has been noted since 1927 and is seen in over 85% of patients.[4] With such history and prevalence, researchers worldwide have studied the etiology, diagnosis, and predisposing factors that contribute to this phenomenon.

External apical root resorption (EARR) is often defined as the "blunting and shortening of root apex caused by the pathologic loss of the cementum and dentin."[4] Comparison of radiographs before and after orthodontic treatment can show loss of root structure and most commonly affect the maxillary incisors, followed by mandibular incisors.[1,5] Though most reported cases of EARR are asymptomatic, the process is irreversible and can lead to unfavorable crown-root ratios and adverse periodontal sequelae.[1,4,5,8]

While EARR remains a prevalent side effect of orthodontic treatment, several studies have sought to conclude what specific factors may contribute to this biologic response, and what precautions can be taken to minimize the severity.

Etiology

External apical root resorption is primarily a biologic response mediated by cellular signaling pathways.[6] As the tooth undergoes compression and tension during orthodontic movement, cementum is resorbed and repaired in a physiologic remodeling process. Chan et al conducted a study and found that in a sample of 36 premolars in 16 patients, more resorption was present in areas of compression compared to areas of tension. They also found that areas of heavy compression (225g) showed higher incidence of resorption compared to lighter compression (25g).[21] External root resorption is induced by applied forces that are greater than the physiologic limits, in combination with alterations in the Wnt/B-catenin and RANK/RANKL signaling pathways.[6]

As forces are applied to the root, an inflammatory response takes place. Although inflammation allows teeth to undergo translation, it also provides the basic mechanism for resorption.[16] When examining the inflammatory response of EARR, Brezniak et al define the resorption process with three degrees of severity:

1. Cemental or surface resorption with remodeling. The outer layers of cementum are resorbed and later fully remodeled.
2. Dentinal resorption with repair. The cementum and outer layers of dentin are resorbed and repaired with cementum material. The shape of the root may be altered.
3. Circumferential apical root resorption. Full resorption of the hard tissue components of root apex, root shortening evident.[22]

The authors note that once the third degree is reached, no regeneration of the root is possible.

Although several areas of the root are subject to compressive forces during orthodontic movement, most resorption takes place in the apical third.[6] Feller et al explain that orthodontically induced root resorption is most commonly seen at the apex, rather than the cemento-enamel junction, due to the thick alveolar bone that encloses the apex of the root. This bone is much less elastic than the thinner alveolar bone seen at the cervical third, and therefore is unable to absorb more of the mechanical stress induced by orthodontic movements.[6,16] Furthermore, the stress per unit surface area is much higher at the apical third than the cervical region.[6]

Although EARR is irreversible, loss of the apical part of the root has minor consequences on overall periodontal support.[5,6] Topkara et al state that "3mm of apical root loss is equivalent to 1mm of crestal bone loss."[5] Furthermore, an evaluation of patients 14 years after orthodontic treatment showed that only 2% experienced tooth loss or hypermobility.[5]

Incidence

The prevalence of external apical root resorption is thought to range from 73-90% in orthodontic patients.[1,2,3,5] Weltman et al state that most apical root resorption is less than 2.5 mm and most orthodontic patients exhibit minor to moderate changes. Severe resorption, exceeding 4mm, is seen in 1-5% of teeth.[2] Other studies claim that incidence of severe resorption is much higher. Marques et al claim in their study of 1049 patients, 14.5% exhibited resorption greater than 1/3 of the original root length.[6,23]

The maxillary incisors are often thought to be the most susceptible to resorption.[5,6,8,9] Weltman et al conducted a systematic review of orthodontically induced root resorption. 921 articles were initially reviewed, and 11 randomized control trials fulfilled the criteria for inclusion, excluding any retrospective studies. The authors concluded from the meta-analysis that maxillary incisors average more apical root resorption than any other tooth, followed by the mandibular incisors and first molars.[2]

Remington et al confirmed these findings by conducting a study of 100 patients treated at the University of Washington Department of Orthodontics. T1, T2 and T3 periapical radiographs were examined to evaluate changes in root length and contour. Similar to the findings in Weltman's systematic review, maxillary incisors were found to be affected the most and to a more severe extent. Long term follow-up (mean=14.1 years) radiographs showed no evidence of increasing root resorption after termination of treatment.[9]

It is often postulated that teeth with blunted or misshapen roots are more susceptible to EARR.[8,10] There is confounding evidence to support this. Brin et al conclude that unusual root morphology only slightly increases the incidence of EARR, but the difference compared to normal roots was not statistically significant.[15] On the contrary, Lopatiene et al note in their systematic review that lateral incisors with abnormal root shapes such as pipette shaped, pointed or dilacerated, are considered to be more susceptible to the most severe resorption.[16]

Diagnosis

When diagnosing external apical root resorption, there are varying degrees of severity. Wendy Sharpe initially created a scoring criterion in 1987 to help quantify the degree of resorption present.[24] Studies published more recently base their criterion based on Sharpe's method, but with more quantitative values. Although studies vary with their exact scoring system, the following is a commonly used evaluation method:

0= No evidence of EARR, ARR= 0 mm

1= Slight blunting of root apex, ARR= 1-2mm

2= Moderate blunting of root apex up to ¼ of root length, ARR= 2mm-1/4 root length

3= Excessive blunting of root apex beyond ¼ of root length, ARR > ¼ root length[1]

Diagnosis of EARR is most frequently done radiographically but can also be done histologically. Histologic studies report far greater incidence compared to radiographic diagnosis, with an incidence greater than 90%.[2,5] Periapical and panoramic radiographs are the two most commonly used diagnostic methods.[5]

The use of panoramic and periapical radiographs to diagnose EARR poses a set of problems. Resorption is a three-dimensional event, and both panoramic and periapical radiographs are limited in their two-dimensional application. There has been controversy regarding whether or not these types of two-dimensional radiographs are accurately accounting for the incidence of resorption.[5] Yuan Li et al state that "It has been found that panoramic radiography may overestimate the prevalence of ARR by 20% compared with periapical radiography, and underestimate compared with microtomography."[1]

With such limitations exhibited in two-dimensional imaging, more clinicians are turning to three-dimensional technology.[5] Cone beam computed tomography (CBCT) provides three-dimensional imaging that allows practitioners to evaluate pathology, lesions and resorption in more accurate dimensions and less radiation exposure is used in comparison to medical CT scanners.[7]

Patel et al conducted an in vivo investigation to compare CBCT and periapical radiography in detection and management of resorption lesions. Patients with internal resorption, external cervical resorption, and no resorption (control) had both CBCT and intraoral radiographs taken. Examiners were shown each of the images (both CBCT and periapical radiographs) and asked to identify internal or external resorption by selecting a treatment plan for each image. There was a significantly higher prevalence of correctly diagnosing and selecting the correct treatment plan with CBCT compared to intraoral radiographs. The authors conclude that although a small sample size was used, CBCT was shown to be more effective and reliable in detecting the presence of resorption lesions.[7]

Furthermore, Mao et al conducted a study to compare diagnostic accuracy of CBCT in comparison to panoramic imaging. The authors used 225 sets of panoramic radiographs and CBCT images with biopsy-proven histopathological diagnoses. Two oral and maxillofacial radiologists were asked to evaluate the images, answer questions regarding characteristics of each lesion, and provide differential diagnoses with confidence scores. The results showed that CBCT has greater diagnostic accuracy when compared to panoramic radiographs, specifically for lesions present in the anterior maxilla. The radiologist examiners also had greater confidence when using CBCT.[20] Although this study was not directly used to analyze root resorption, most resorption occurs in the maxillary centrals, and we can assume that CBCT would also provide a superior diagnostic tool.

Contributory Treatment Factors

With a clear understanding of the high incidence of orthodontic-induced EARR, several studies aim to address what factors contribute to the prevalence and severity. Factors that pertain to treatment options such as extractions, orthognathic surgery, type of bracket/appliance, and treatment duration have been studied to determine their effect on EARR.

Four bicuspid extractions are a common orthodontic treatment option that provide a reliable approach to solve arch length discrepancy and improve facial esthetics. Jiang et al used 96 subjects to determine if extraction therapy shows higher incidence of EARR. The patients of the study ranged from 9-34 years old, consisting of 34 males and 62 females. All participants underwent at least 12 months of fixed appliance orthodontics, with treatment duration averaging 31 months. Patients who required any type of orthognathic surgery were excluded. 65 of the 96 subjects underwent 4 bicuspid extractions. T1 and T2 panoramic radiographs were used to evaluate maxillary and mandibular incisors, canines, premolars, and first molars. The authors found that the patients who had underwent extraction therapy had a statistically significant higher mean root resorption score on the lower anterior teeth. No statistically significant correlation was found in the posterior dentition. The authors note that these findings could be due to the fact that the retraction of the mandibular incisors after premolar extractions could be influenced by the thin cortical plate in the mandibular anterior region.[18]

Similar to Jiang et al's findings, Motokawa et al also found that patients who receive orthodontic extractions have higher prevalence of severe root resorption. Motokawa's study evaluated 243 patients. The patients were divided into the following groups: extraction, non-extraction, surgical, and non-surgical treatment. The average age of the patients was 18.9 years and average treatment time was 2.4 years. Periapical radiographs were analyzed and EARR was defined as 0= no root resorption, 1=irregular root contour, 2= ARR <2mm, 3= ARR 2mm-1/3 of root length, 4= ARR > 1/3 original root length. Severe resorption was defined as being in the 3-4 range. The results showed that although there was no statistically significant difference in the prevalence of EARR (number of teeth affected), there was a significantly greater prevalence of severe resorption in patients with extractions. There was no significant difference in relation to the surgical vs non-surgical groups.[4]

In addition to extraction vs non extraction treatment, the direction of tooth movement can also affect EARR.[10] Linkous et al studied which vector specifically is seen with the greatest apical root resorption. This study evaluated 93 patients with pre-treatment class I molar relationships. 46% of the patients were treated with 4 bicuspid extractions. The average age was 13.6 years, and the average treatment time was 1.76 years. All patients followed a similar archwire progression sequence and powerchains with elastics were utilized to close extraction spaces in the extraction group. CBCT images were analyzed to measure root lengths of maxillary incisors. This study used predictors of type of treatment (extraction vs non-extraction) as well as 8 ratio-scale variables: mediolateral change in facial CEJ location, anteroposterior change in CEJ, craniocaudal change in CEJ, mediolateral change in incisor root apex position, anteroposterior incisor apex movement, craniocaudal apex movement, amount of root torqueing in parasagittal plane, and treatment duration. These vectors allowed the authors to conclude that although all directions increase risk of EARR, intrusion is the most "deleterious sort of tooth movement"[10] and the strongest predictor of EARR. The study showed that for 1mm of intrusion, there was an average of 1.03mm of EARR. Patients with extractions also had statistically significantly greater EARR in comparison to non-extractions.[10]

Although the previous study provided data that intrusion was a strong predictor of EARR, Costopoulos et al's research found otherwise. 17 patients from the University of Connecticut School of Dental Medicine were evaluated. All 17 patient's treatment plan included 2-4mm of overbite correction. The average age of the experimental group was 16.4 years, and the average age of the control group was 16.1 years. The 17 patients were treated with a Burstone-type intrusion arch, which delivered a force of 15gm/tooth. The force levels were checked at each visit with a force gauge. Periapical radiographs before and after intrusion (approximately 4.6 months) were compared to measure the amount of resorption. The average amount of intrusion in the experimental group was 1.9mm at a rate of 0.41mm/month. The experimental group had an average of 0.6mm of resorption seen on the central incisors, while the control had an average of 0.2mm. Statistical analysis showed that the difference in the patients who underwent intrusion was not statistically significant.[25]

In addition to the type of treatment planned for patients, the type of bracket and appliance have also been evaluated as possible contributory factors of EARR. Jianru Yi et al conducted a systematic review to compare EARR in patients with self-ligating and conventional brackets. Randomized control trials, controlled clinical trials, and cohort studies were eligible for analysis. Five studies were included in the review, and the results are quite intriguing. The analysis found that self-ligating brackets were found to have a long-term protective effect on maxillary central incisors from EARR compared to traditional brackets (standard mean difference -0.31)[3]. There was no difference in bracket choice for maxillary lateral incisors, mandibular lateral or mandibular central incisors. The authors discuss that self-ligating brackets may deliver less force to teeth during initial alignment compared to conventional brackets, which may be a desirable effect for patients who are at higher risk for resorption. The studies varied in the method of outcomes (root resorption measured in mm or percentage) and type of imaging (periapical, panoramic, CBCT).[3] While the results of this meta-analysis are promising in regard to maxillary centrals, more data is needed to confirm these conclusions.

Clear aligners have become increasingly popular over the last few years. Yuan Li et al considered the difference in prevalence and severity of EARR using clear aligners rather than traditional fixed appliances. 70 subjects with similar American Board of Orthodontic (ABO) discrepancy scores were evaluated. One group used Invisalign aligners as treatment modality, while the other group used 3M Unitek fixed appliances. The average age of the patients was 23.61 years. Root length of each anterior tooth was measured via CBCT images and ARR was measured by calculating the difference between the root lengths before and after orthodontic treatment. The results of this study showed that EARR was significantly lower in the clear aligners group compared to the fixed appliances group. The highest incidence of EARR was found on the lateral incisors of patients in fixed appliances (maxillary 88.52%, mandibular 88.33%). The lowest incidence was found on canines of patients in clear aligners (maxillary 45%, mandibular 35.38%). The severity was calculated using Sharpe's method.[24] The severity of EARR in the clear aligners group was also significantly lower compared to the fixed appliance group.[1]

EARR can be detected in the early stages of orthodontic treatment.[8,9] In a systematic review of twenty-four articles, Lopatiene et al discovered that treatment time is significantly correlated with root resorption. The average treatment time for patients with root resorption was 2.3 years, while the average treatment length for patients without resorption was 1.5 years. The authors cite that studies have shown that in the first 6-9 months of treatment, resorption was detected in 34% of teeth. This incidence increases to 56% at 19 months of treatment.[16]

Predisposing Patient Factors

The previous studies are vital in our knowledge of orthodontic treatment factors that may contribute to external apical root resorption. While these provide clinicians with information and evidence of the safest way to treat patients, it is also important to take into account additional patient factors that may contribute to EARR. Lopateine et al state that "individual susceptibility is the main risk factor for root resorption in orthodontic patients."[16] Ethnicity, gender, age, and even genetics may play a role in the amount and severity of resorption seen in orthodontic patients and are equally imperative.

There is data that supports that patients of different ethnic backgrounds have differences in crown to root ratios in permanent dentition. Some studies claim that EARR is less frequently seen in Asians compared to Caucasian or Hispanic patients.[16] Although there have been limited studies that directly examine the correlation between ethnicity and EARR, it is understood that patients with reduced root/crown ratio are at increased risk of root resorption during orthodontic treatment.[11] Wang et al conducted a retrospective study of 333 patients at the University of Alabama at Birmingham School of Dentistry. The authors of this study postulated whether African Americans, Caucasians and Hispanics have varying root/crown ratios. Panoramic radiographs of patients of each ethnic background were analyzed. Patient age ranged from 9-50 years old and only permanent dentitions were included. Patients with previous orthodontic treatment, craniofacial anomalies, or history of trauma were excluded. The study showed that Hispanic patients had significantly lower R/C ratios in most teeth compared to Caucasians and African Americans. This study exemplifies that ethnicity may play a role in tooth morphology. The authors note that these low ratios may result from resorption of fully developed roots, or extrinsic or genetic causes.[11]

Patient age is also a commonly thought risk factor for orthodontically-induced EARR.[2,16] Pastro et al investigated different factors that are associated with resorption through means of a retrospective study. 600 patients who had been previously treated at a Graduate Orthodontic clinic in Brazil were evaluated. All patients underwent fixed orthodontic appliance therapy with the same methodology and general archwire sequence. Periapical radiographs of maxillary and mandibular incisors were assessed, and the patients were classified into two groups: absent/mild root resorption or moderate/severe root resorption. The two groups were compared with one another to evaluate predisposing factors. The authors found that there was no correlation between initial age and resorption. Pastro et al also concluded in their study that gender, type of malocclusion, parafunctional habits, and allergies did not show statistically significant differences in EARR.[17]

Similar to Pastro et al's article, Ruo-ping Jiang et al also investigated different contributory factors that play a role in EARR. Though the findings regarding extraction vs non-extraction cases were previously discussed, the authors also evaluated gender, age and treatment duration. The study consisted of 34 males and 62 females, with an average treatment time of 31 months. The results showed that there was no statistically significant difference between males in females in regard to root length at T1 and T2. However, treatment duration showed a statistically significant difference. The results regarding age were defined as inconclusive. A positive correlation between age and root resorption was seen in maxillary teeth, but no correlation was found between age and mandibular anterior or posterior teeth.[18]

Mirabella et al used periapical radiographs of maxillary anterior teeth of 343 adult patients to explore additional risk factors. The mean age of patients was 34.5 and the average treatment time was 2 years. T1 and T2 radiographs of maxillary anterior teeth were analyzed to measure EARR. The results showed that earlier orthodontic treatment was actually a preventative factor for resorption of lateral incisors and canines. Type of initial malocclusion, treatment time, use of rectangular archwires, and proximity of the root to the palate had no statistically significant association with root resorption. Amount of root movement and presence of long, deviated roots increased the risk for apical root resorption. Furthermore, use of elastics may be a risk factor for EARR on the teeth that support the elastics, however statistical analysis had a very low variance, and more research is needed to confirm these findings.[19]

Al-Qawasmi et al questioned whether genetic predisposition had an effect on external apical root resorption. To test this hypothesis, researchers examined interleukin-1 (IL-1A and IL-1B) genes and their association with EARR. 35 families with at least 2 children who received comprehensive orthodontic treatment were analyzed. Parents and children were asked to participate, with the mean time between T1 and T2 records being 2.82 years. Roots of maxillary central incisors, mandibular central incisors and mandibular first molars were analyzed on panoramic radiographs of the previously treated patients. For each patient, the tooth with the maximum EARR was selected as the dependent variable. Swabs of buccal mucosa from the 35 families were collected and genomic DNA was obtained via the Puregene method. Linkage and association methods of analysis were conducted to determine the association between the incidence of EARR and polymorphism of interleukin-1. The results showed that there was statistically significant evidence that IL-1B polymorphism accounts for 15% of the total variation of maxillary incisor EARR. Participants homozygous for the IL-1B allele had an increased risk of EARR greater than 2mm in comparison to participants who were not homozygous for the IL-1B allele.[12] These notable findings prove that there are supplementary factors that contribute to EARR besides the previously known orthodontic treatment modality and force variation.

Rapid Maxillary Expansion

Rapid maxillary expansion (RME) is an orthodontic treatment modality used to correct maxillary transverse discrepancies.[13] The technique was first described in 1860 and remains a common practice to this day. RME produces heavy forces to the dentition and bones of the face, overcoming the limit for orthodontic tooth movement and causing the midpalatine suture to open in a nonparallel and triangular way. 2-5kg of force can be produced by each turn of the RME appliance, leading to a total force of 9-12kg.[13]

Often, RME appliances are used at the start of orthodontic treatment to correct maxillary transverse discrepancies. RME is usually required for 2-3 weeks, then the appliance is left in place for a retention period, often recommended of 3 months, to allow for bone to fill into the separated suture.[13]

One of the most spectacular changes seen in RME is diastema formation between the upper central incisors. Agarwal et al estimate that "the incisors separate approximately half the distance the expansion screw has been opened." The diastema often spontaneously closes during the retention period or may be closed in orthodontic treatment.[13]

There are several types of RME appliances available. The two most recognized in the literature are the Hyrax, a tooth borne expander, and the Haas, a tooth and tissue borne expander.[26] Weissheimer et al compared the immediate effects of RME between the Hyrax and Haas and found that both were efficient in correcting transverse maxillary discrepancy. Although the Hyrax produced greater orthopedic effects than the Haas, the difference was not clinically significant.[27]

A study by Baysal et al evaluated the resorption of posterior teeth after rapid maxillary expansion with Hyrax. The maxillary first premolar and first molar served as anchor teeth for the appliance, but the second premolar was not. CBCT records were compared pre and post expansion. All maxillary premolars and first molars were shown to have root volume loss. The mesio-buccal root of the molar showed the highest mean volume loss, followed by the premolars and the disto-buccal root of the molar, who demonstrated comparable volume loss.[14]

CHAPTER TWO

MAXILLARY CENTRAL INCISOR RR IN HISPANIC AND NON-HISPANIC WHITE PATIENTS WITH RME

Abstract

Introduction: Apical root resorption is one of the most common adverse effects of orthodontic treatment. Forces used during orthodontic tooth movement can cause permanent loss of apical surfaces of teeth and although most reported cases of root resorption are asymptomatic, the process is irreversible and often unpredictable. Thus, it is of clinical interest to investigate which patients may be at greatest risk.

Purpose: This study utilized Cone Beam Computed Tomography (CBCT) to evaluate whether rapid maxillary expansion (RME) in Hispanic patients increased the severity of orthodontically induced apical root resorption.

Materials and Methods: Pre-treatment (T1) and post-treatment (T2) Digital Imaging and Communications in Medicine (DICOM) CBCT images of patients treated at Loma Linda University were imported into OsiriX MD software (version 12.5.2, Pimeo, Bemex Switzerland) for tooth length measurement of maxillary central incisors in sagittal and coronal views. The amounts of root resorption (RR) were calculated and compared between Hispanic and Non-Hispanic White patients treated with and without RME using analysis of covariance (ANCOVA). Spearman Rho correlation tests and Chi-squared analysis were performed to evaluate the relationship between RR and age, gender, and treatment time. All statistical analyses were performed at $\alpha = 0.05$.

Results: A total of 180 patients were included in this study. Non-Hispanic White patients that underwent rapid maxillary expansion experienced greater amounts of root resorption ($p > .05$) compared to Hispanic and non-expansion patients. There were no

statistically significant differences in overall RR comparing expansion and non-expansion groups, or between ethnicities ($p > .05$). Age, treatment time, and gender showed no statistically significant correlation with RR ($p > .05$).

Conclusions: Non-Hispanic White patients that underwent rapid maxillary expansion experienced statistically, but not clinically, significant higher levels of root resorption. Age, treatment time and gender had no effect on RR.

Introduction

Statement of the Problem

External apical root resorption is one of the most common iatrogenic consequences of orthodontic treatment.[1] In most cases, apical root resorption is less than 2.5 mm and patients exhibit minor to moderate effects. Severe resorption, exceeding 4mm, is seen in 1-5% of teeth.[2] While most reported cases of apical root resorption are asymptomatic, the process is irreversible and can lead to unfavorable crown-root ratios and adverse periodontal sequelae.[2,3,4,5]

Apical root resorption is primarily a biologic response mediated by cellular signaling pathways.[6] As teeth undergo compression and tension during orthodontic movement, cementum is resorbed and repaired in a physiologic remodeling process. Several areas of the root are subject to compressive forces during orthodontic movement, but most resorption takes place in the apical third.[6]

Existing studies evaluating root resorption often utilize panoramic and periapical radiographs. Resorption is a three-dimensional event, and both panoramic and periapical radiographs are limited in their two-dimensional application.[5] Cone beam computed tomography (CBCT) provides three-dimensional imaging that allows practitioners to evaluate resorption in more accurate dimensions and less radiation exposure is used in comparison to medical CT scanners.[7]

The maxillary incisors are most susceptible to root resorption.[5,6,8,9] While studies can substantiate which teeth are most often affected, it is difficult to assess which patients are at greatest risk. Contributory factors such as genetics, amount of tooth movement during orthodontic treatment, and crown-to-root ratios have been postulated to have a correlation with root resorption.[10,11,12]

Rapid maxillary expansion (RME) is a vital orthodontic treatment modality used to correct maxillary transverse discrepancies and arch length discrepancies. Most expansion is performed via a Hyrax or Haas appliance. RME can produce a cumulative force of 9-12kg to the dentition and bones of the face.[13] One of the most prominent effects seen in RME is diastema formation between the upper central incisors, which spontaneously closes during the retention period or is closed in orthodontic treatment following RME.[13]

In Southern California, Hispanic patients make up a large percentage of the patient population. The purpose of this study was to determine whether Hispanic patients who undergo rapid maxillary expansion experience higher rates of apical root resorption. CBCT scans of the maxillary central incisors were evaluated before and after orthodontic treatment to assess the difference in root length.

Hypothesis

The null hypothesis stated no statistically significant difference between the amount of apical root resorption and rapid maxillary expansion in Hispanic patients. A second null hypothesis stated no correlation between root resorption and patient's age, gender, and treatment time.

Materials and Methods

Patient Selection

This study was approved by the Institutional Review Board (IRB) of Loma Linda University (LLU), Loma Linda, CA. Records were obtained of patients treated at the Loma Linda University Orthodontic Graduate clinic between 2001 to 2022 with pre-treatment (T1) and post-treatment (T2) CBCT radiographs. Patients were classified into four groups:

1. Hispanic patients treated with rapid maxillary expansion (RME)
2. Non-Hispanic White patients treated with RME
3. Hispanic patients treated without RME
4. Non-Hispanic White patients treated without RME

One examiner (MH) performed all measurements and data collection. Patient selection was based on the following inclusion/exclusion criteria listed in Table 1:

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria
1. Comprehensive orthodontic treatment at LLU with fixed orthodontic appliances 2. Hispanic or Non-Hispanic White patients 3. Age 9-30 years old 4. Rapid maxillary expansion appliance (Hyrax, Haas) 5. Presence of maxillary central incisors with complete root formation prior to start of treatment 6. Complete CBCT records at T1 and T2 (2001 - present)
Exclusion Criteria
1. Clear aligner therapy cases 2. Surgical cases 3. Extraction cases 4. Treatment duration exceeding 36 months 5. Medical history of autoimmune diseases or arthritis 6. Any form of trauma to maxillary central incisors before or during ortho treatment 7. Any form of endodontically treated maxillary central incisors 8. Large class IV restorations on maxillary central incisors

Data Collection

Records from patients who met the selection criteria were reviewed and the following data recorded:

- Gender
- Age at beginning of comprehensive treatment (years)
- Ethnicity (Hispanic, Non-Hispanic White)
- Treatment time duration (months)

One hundred and eighty patients were included in this study. Ninety patients identified as Hispanic, and the other ninety identified as Non-Hispanic White. 50% of the patients were female, and 50% were male. The mean age of the patients was 13.6 years, with a range of 9 to 26 years. The average time in treatment for the sample was 26.8 months, with a range of 14 to 36 months. The majority of patients in the rapid maxillary expansion groups used a Hyrax expander, four patients used a Haas.

Table 2: Descriptive Statistics for Patients

	RME Hispanic	RME Non-Hispanic White	Non-RME Hispanic	Non-RME Non-Hispanic White
Males	22	27	24	17
Females	23	18	21	28
Mean Age (years) [Range]	12.5 [9-16]	13.5 [9-17]	13.8 [10-22]	14.4 [11-26]
Mean Treatment Time (months) [Range]	27.6 ± 5.93 [14-36]	26.7 ± 4.93 [17-35]	27.5 ± 5.5 [20-36]	25.6 ± 4.23 [20-36]

CBCT records of patients who met the criteria were anonymized and imported into OsiriX MD (version 12.5.2, Pimeo, Bernex, Switzerland) as Digital Imaging and Communication in Medicine (DICOM) files. The 3D multi-planar reconstruction view (MPR) was utilized to position the scan in a standardized way and orient the axis lines. The y-axis was oriented along the long axis of the tooth and the x-axis intersected the mesiodistal center of the crown (Figure 1). The sagittal and coronal views were each enlarged and isolated for measurement (Figure 2).

The length of the incisor was measured by identifying two points, the root apex and the incisal tip. The incisal tip was defined as the midpoint between the mesial-distal width of the crown. A digital point was placed on the root apex and the incisal tip, and the root length was measured and recorded (Figure 3).

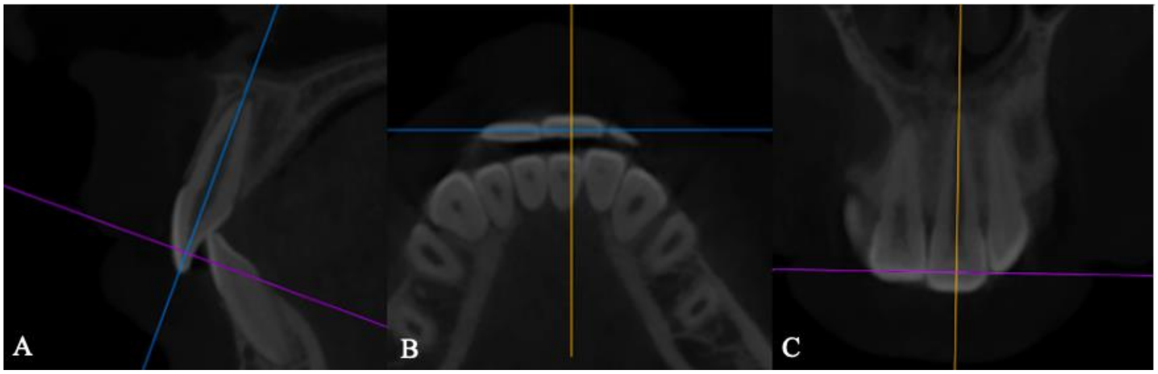

Figure 1: MPR Orientation. Maxillary central incisor with axis lines centered on the long axis and center of the crown **A)** Sagittal View **B)** Axial View **C)** Coronal View

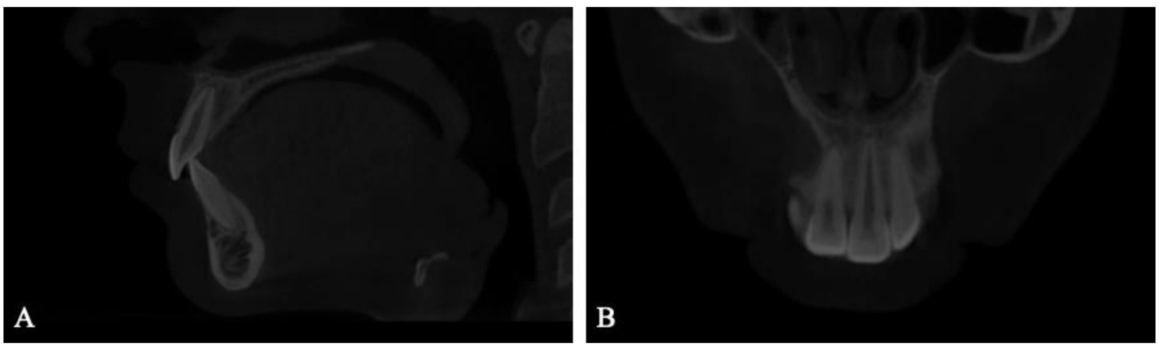

Figure 2: Enlarged Views. Maxillary central incisor in **A)** Sagittal View **B)** Coronal View

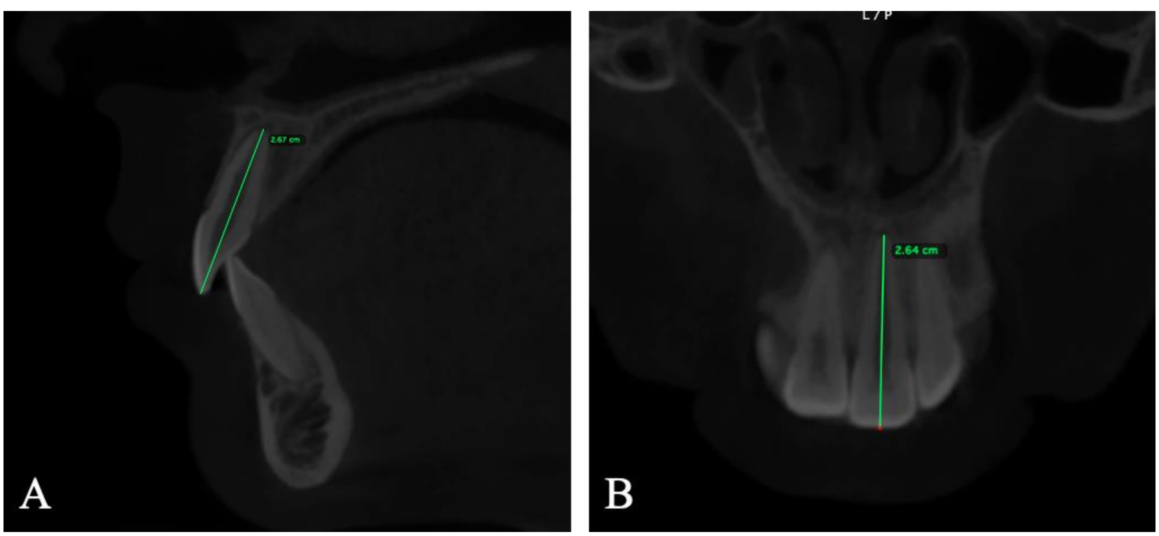

Figure 3: Measurement of Maxillary Central Incisor Root**. A)** Sagittal and **B)** Coronal measurement from incisal edge to apex of maxillary central incisor

Of the 360 teeth evaluated, seven showed curvature in the apical third. The Osirix MD (version 12.5.2, Pimeo, Bernex, Switzerland) curved line tool was utilized to draw a more accurate line from the incisal tip to the root apex (Figure 4).

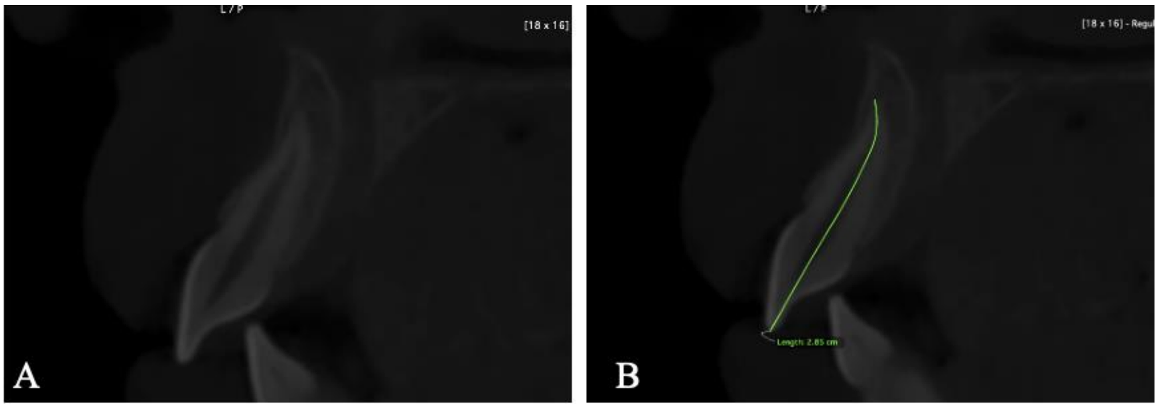

Figure 4: Measurement of Curved Root. **A)** Maxillary central incisor with curved apical third **B**) Osirix MD Curved Line tool used for measurement

This process was performed on both right and left maxillary central incisors and repeated on all T1 and T2 CBCT images. The amount of root resorption was calculated by subtracting the T2 root length by the T1 root length. The average of the sagittal and coronal values and the right and left values were calculated to obtain the mean resorption value per patient.

Statistical Analysis

Both central maxillary incisors were measured and analyzed for each patient in the sagittal and coronal view. The four patient groups (Hispanic with RME, Non-Hispanic White with RME, Hispanic Control, Non-Hispanic White Control) were treated as categorical independent variables. This study required a sample size of 45 per group to have 80% power to find an effect size of 0.6 (moderate size).

Analysis of covariance (ANCOVA) was performed between the four patient groups to assess statistically significant differences in root resorption. Spearman Rho correlation coefficients expressed the correlation between RR and age and treatment time, and Chi-squared analysis was performed to evaluate RR and gender.

Reliability of measurements were assessed using repeated measurement intra-class correlation tests on 60 randomly selected patients four weeks following initial data collection. For all statistical analyses the significance level was set at $\alpha = 0.05$.

Results

Of the 180 patients evaluated in this study, the majority had mean resorption values between 0-1mm. Table 3 shows the distribution of RR mean values among the four patient groups.

Table 3: Root Resorption Distribution Among Patient Groups

	# of patients			
Mean resorption value (mm)	RME Hispanic	RME Non-Hispanic White	Non-RME Hispanic	Non-RME Non-Hispanic White
0-1	26	17	34	29
1-2	13	17	9	14
2-3	5	9	1	2
3-4	1	1	0	0
4+	0	1	1	0

Measurements were repeated on 60 patients and intraclass correlation coefficients of greater than 0.9 were observed in all measurements, indicating highly reproducible methods.

The four patient groups showed similar rates of RR, with all mean values within 1mm. Comparisons of mean RR between the study's four patient groups showed that Non-Hispanic White patients with RME had statistically significant higher rates of RR ($p > .05$; Table 4).

Table 4: Root Resorption Mean Values. Comparison of RR between Hispanic and Non-Hispanic White patients with and without RME at $\alpha = 0.05$

	Mean ± SD of Root Resorption (mm) [Range]		P-value
	RME	Non-RME (Control)	
Hispanic	0.99 ± 0.91 [0.10 – 3.73]	0.71 ± 1.20 [0.10 – 4.88]	.216
Non-Hispanic White	1.45 ± 1.21 [0.20 – 5.03]	0.91 ± 0.70 [0.05 – 2.83]	.011*

* Statistically significant difference

When comparing patients with and without RME, regardless of ethnicity, patients with RME had slightly higher levels of RR than without RME. The values were not statistically significant ($p > .05$; Table 5).

Table 5: Overall RR Based on Expansion. Comparison of RR between RME and non-RME patients at α = 0.05

	Mean ± SD of Root Resorption (mm) [Range]		P-value
	RME	Non-RME (Control)	
Hispanic + Non-Hispanic White	1.22 ± 1.23 [0.10 – 5.03]	0.81 ± 1.21 [0.05 – 4.88]	.115

* Statistically significant difference

Comparison of the amount of root resorption between ethnicity showed that Non-Hispanic White patients experienced slightly more RR than Hispanic patients, but the results were not statistically significant ($p > .05$; Table 6).

Table 6: Overall RR Based on Ethnicity. Comparison of RR between Hispanic and Non-Hispanic White patients at α = 0.05

	Mean ± SD of Root Resorption (mm) [Range]		P-value
	Hispanic	Non-Hispanic White	
RME + Non-RME (Control)	0.85 ± 1.20 [0.10 – 4.88]	1.18 ± 1.25 [0.05 – 5.03]	.205

* Statistically significant difference

Spearman Rho correlation analyses were performed to assess the correlation between root resorption and other variables. Age and treatment time had no statistically significant correlation with root resorption ($p > .05$; Table 7).

Table 7: Overall RR and Other Variables. Correlation Coefficient (Spearman's Rho) between RR and Other Variables at $\alpha = 0.05$

Variable	Correlation (r)	P-Value
Age	0.123	.101
Treatment Time	0.050	.500

* Statistically significant difference

There was an equal amount of male and female patients included in the study (Table 8). Chi-squared analysis showed no difference in RR between males and females ($p > .05$; Table 8).

Table 8: Overall RR and Gender. Chi-squared test for comparison of RR between gender at $\alpha = 0.05$

		Expansion Group		Total
Gender		RME	Non-RME	
F	Observed (% within column)	41 (45.6%)	49 (54.4%)	90 (50%)
M	Observed (% within column)	49 (54.4%)	41 (45.6%)	90 (50%)
Total	Observed (% within column)	90 (100%)	90 (100%)	180 (100%)

p = .233

* Statistically significant difference

Discussion

Apical root resorption remains one of the most common iatrogenic consequences of orthodontic treatment.[1] While many precautions are taken throughout treatment, almost all patients experience some degree of root resorption.[2] Luckily, most resorption seen is less than 2.5mm and most patients will not exhibit any adverse consequences. Severe resorption, defined as apical resorption exceeding 4mm, does not occur often, with reported 1-5% of teeth affected according to the literature.[2] This study demonstrated similar findings. All teeth included in the study demonstrated some degree of mild root resorption with a very small percentage, less than 1%, classified as severe resorption (Table 3).

Each patient group analyzed in this study experienced similar degrees of apical root resorption with mean root resorption values all under 1.5mm. Non-Hispanic White patients with rapid maxillary expansion had the highest rates of root resorption compared to Hispanic and non-RME control groups (Table 4). Although statistically significant, the differences between the mean maxillary central incisor resorption values were within less than a millimeter, demonstrating little clinical significance.

This study concluded that patients who undergo rapid maxillary expansion as part of their orthodontic treatment do not undergo higher rates of root resorption. Past studies have confirmed that RME patients experience more resorption, but have focused solely on the anchor premolar and first molar teeth.[14] Central maxillary incisors are also impacted during rapid maxillary expansion as RME produces heavy forces on the dentition and bones of the face, and the maxillary central incisors are separated as the mid-sagittal suture opens. Agarwal et al estimates they separate "approximately half the distance the expansion screw has been opened."[13] The rapid diastema formation is most often immediately closed with fixed orthodontic appliances for patient esthetics.

With such rapid movement of the maxillary central incisors during expansion, this study aimed to determine whether these teeth are more likely to experience root resorption compared to teeth that do not undergo RME. Table 5 exhibits that for both Hispanic and Non-Hispanic White patients, there was no statistically significant difference in resorption in RME patients.

Ethnicity has also been suspected of having a correlation with orthodontic root resorption. Wang et al conducted a study that concluded non-orthodontic Hispanic patients have shorter root/crown ratios compared to Caucasians.[11] Other studies have theorized that short, blunted roots are more susceptible to RR, though the findings showed very slight increase in incidence.[15]

The findings in this study showed that Non-Hispanic White patients had slightly higher rates of root resorption than Hispanic patients (Table 6), though the differences were not statistically significant. These findings contradict previous studies that found Hispanic patients to have greater root resorption compared to Caucasians and Asians.[16] Including additional ethnicities in this study would have provided a more thorough analysis of the relationship between ethnicity and root resorption, but data was limited due to geographical location and patient population.

The average treatment time of all patients evaluated in this study was 26.9 months, and the average age was 13.6 years. Results show that there was no correlation between age and root resorption (Table 7). Past studies have shown contradicting results regarding the relationship between age and resorption. A study by Pastro et al[17] concluded there is no correlation, while a different study stated that age has a correlation in maxillary teeth, but not in mandibular anterior or posterior teeth.[18]

Both Lopatiene et al[16] and Ruo Ping Jiang et al[18] have shown there is a strong correlation between treatment time and root resorption, and therefore our study excluded treatment times exceeding 36 months. The average treatment time in this study was 26.9 months and there was no statistically significant correlation between treatment time and resorption (Table 7). This concurs with Mirabella et al[19], whose average treatment time was 24 months and found no correlation with root resorption.

This study was comprised of an equal number of males and females, and there was no statistically significant difference between gender and resorption (Table 8). This is similar to the findings of Pastro et al[17] and Ruo Ping Jiang[18], who also concluded no correlation between the two.

The null hypothesis stating that no statistically significant difference existed between the amount of apical root resorption and rapid maxillary expansion in Hispanic patients was rejected by the study. Although there were statistically significant differences among the mean root resorption of the four patient groups, the differences were within less than 1mm, which is likely not clinically significant.

Despite the high incidence of orthodontic root resorption, the results of this study indicate most resorption to the maxillary central incisors is modest, even in cases of rapid maxillary expansion. Nevertheless, it is our duty as clinicians to recognize the multi-factorial etiology of resorption and inform patients who may be at greatest risk.

Conclusion

Within the confines of this study, the following conclusions regarding RME on maxillary central incisor root resorption can be drawn:

1. Non-Hispanic White patients with RME experienced statistically significant more RR than Hispanic or Non-RME patients, but the mean difference was < 1mm.
2. RME did not cause more RR.
3. Ethnicity had no effect on RR.
4. Age, treatment time, and gender had no correlation with overall RR.

CHAPTER THREE

EXTENDED DISCUSSION

Study Limitations and Further Directions

This study was limited to only two ethnicities, Hispanic and Non-Hispanic White. Inclusion of other ethnicities was inhibited by geographical location and patient population. Future studies including additional ethnicities will provide a more thorough analysis on the relationship between ethnicity, expansion, and apical root resorption.

The definition of ethnicity is often thought of as belonging to a specific national, cultural, or geographic group. There are no specific qualifications that deem an individual a member of a certain ethnicity, and therefore ethnicity classification is primarily subjective. Future studies may utilize genetic testing and genomic DNA analysis to accurately characterize and distinguish different ethnicities to thoroughly examine if ethnicity is correlated with higher rates of orthodontic root resorption.

Furthermore, a significant portion of the population today consists of blended cultures and ethnic backgrounds. This study did not account for individuals who were of mixed ethnicity, and thus the conclusions cannot accurately reflect all patients.

The use of CBCT scans provides greater diagnostic accuracy than panoramic or periapical radiographs.[7,20] However, another limitation of this study is that the CBCT scans examined the root length in only the sagittal and coronal view. Apical root resorption is a three-dimensional, circumferential process[8], and the cuts used in this study were unable to evaluate the full circumference of the root.

Additionally, by averaging the sagittal and coronal resorption values for each patient, severe resorption on a single view was potentially overlooked. Volumetric analysis of each root would be a more accurate assessment of the resorption that occurred.

While half of the patients in this study underwent rapid maxillary expansion in their orthodontic treatment, the amount of expansion was different for each individual patient. The amount of expansion prescribed for each patient is often a clinical judgement, and therefore the diastema following expansion could have varied greatly per patient. Measurement of the diastema or CBCT scans taken immediately after expansion would provide more data to evaluate the correlation between the amount of rapid maxillary expansion and greater rates of root resorption.

As orthodontic root resorption is of multifactorial etiology, it would also be prudent for future studies to record additional factors that may show greater correlation with resorption. Analysis of root shape morphology and pre-treatment root length were not assessed in this study, but consideration of these factors in future studies could determine if they are associated with more severe orthodontic root resorption.

REFERENCES

1. Li Y, Deng S, Mei L, et al. Prevalence and severity of apical root resorption during orthodontic treatment with clear aligners and fixed appliances: a cone beam computed tomography study. Prog Orthod 2020;21:1.

2. Weltman B, Vig KW, Fields HW, Shanker S, Kaizar EE. Root resorption associated with orthodontic tooth movement: a systematic review. Am J Orthod Dentofacial Orthop 2010;137:462-476.

3. Yi J, Li M, Li Y, Li X, Zhao Z. Root resorption during orthodontic treatment with self-ligating or conventional brackets: a systematic review and meta-analysis. BMC Oral Health 2016;16:125.

4. Motokawa M, Sasamoto T, Kaku M, et al. Association between root resorption incident to orthodontic treatment and treatment factors. Eur J Orthod 2012;34:350-356.

5. Topkara A, Karaman AI, Kau CH. Apical root resorption caused by orthodontic forces: A brief review and a long-term observation. Eur J Dent 2012;6:445-453.

6. Feller L, Khammissa RA, Thomadakis G, Fourie J, Lemmer J. Apical External Root Resorption and Repair in Orthodontic Tooth Movement: Biological Events. Biomed Res Int 2016;4864195:1-7.

7. Patel S, Dawood A, Wilson R, Horner K, Mannocci F. The detection and management of root resorption lesions using intraoral radiography and cone beam computed tomography - an in vivo investigation. Int Endod J 2009;42:831-8.

8. Kocadereli I, Yesil TN, Veske PS, Uysal S. Apical root resorption: a prospective radiographic study of maxillary incisors. Eur J Dent 2011;5:318-323.

9. Remington DN, Joondeph DR, Artun J, Riedel RA, Chapko MK. Long-term evaluation of root resorption occurring during orthodontic treatment. Am J Orthod Dentofacial Orthop 1989;96:43-46.

10. Linkous ER, Trojan TM, Harris EF. External apical root resorption and vectors of orthodontic tooth movement. Am J Orthod Dentofacial Orthop 2020;158:700-709.

11. Wang J, Rousso C, Christensen BI, et al. Ethnic differences in the root to crown ratios of the permanent dentition. Orthod Craniofac Res 2019;22:99-104.

12. Al-Qawasmi RA, Hartsfield JK Jr, Everett ET, Flury L, Liu L, Foroud TM, Macri JV, Roberts WE. Genetic predisposition to external apical root resorption. Am J Orthod Dentofacial Orthop 2003;123:242-252.

13. Agarwal A, Mathur R. Maxillary Expansion. Int J Clin Pediatr Dent 2010;3:139-46.

14. Baysal A, Karadede I, Hekimoglu S, Ucar F, Ozer T, Veli I, Uysal T. Evaluation of root resorption following rapid maxillary expansion using cone-beam computed tomography. Angle Orthod 2012;82: 488–494.

15. Brin I, Tulloch JF, Koroluk L, Philips C. External apical root resorption in Class II malocclusion: a retrospective review of 1- versus 2-phase treatment. Am J Orthod Dentofacial Orthop 2003;124:151-6.

16. Lopatiene K, Aiste D. Risk Factors of Root Resorption after Orthodontic Treatment. Baltic Dental and Maxillofacial Journal 2008;10:89–95.

17. Pastro JDV, Nogueira ACA, Salvatore de Freitas KM, Valarelli FP, Cançado RH, de Oliveira RCG, de Oliveira RCG. Factors Associated to Apical Root Resorption after Orthodontic Treatment. Open Dent J 2018;12:331-339.

18. Ruo-ping Jiang, J.P. McDonald, Min-kui Fu. Root resorption before and after orthodontic treatment: a clinical study of contributory factors, European Journal of Orthodontics 2020;32:693–697.

19. Mirabella AD, Artun J. Risk factors for apical root resorption of maxillary anterior teeth in adult orthodontic patients. Am J Orthod Dentofacial Orthop 1995;108:48-55.

20. Mao WY, Lei J, Lim LZ, Gao Y, Tyndall DA, Fu K. Comparison of radiographical characteristics and diagnostic accuracy of intraosseous jaw lesions on panoramic radiographs and CBCT. Dentomaxillofac Radiol 2021;50:20200165.

21. Chan E, Darendeliler MA. Physical properties of root cementum: part 7. Extent of root resorption under areas of compression and tension. Am J Orthod Dentofacial Orthop 2006;129:504-510.

22. Brezniak M, Wasserstein A. Orthodontically Induced Inflammatory Root Resorption. Part I: The Basic Science Aspects. Angle Orthod 2002;72:175–179.

23. Marques LS, Ramos-Jorge ML, Rey AC, Armond MC, Ruellas AC. Severe root resorption in orthodontic patients treated with the edgewise method: prevalence and predictive factors. Am J Orthod Dentofacial Orthop 2010;137:384-8.

24. Sharpe W, Reed B, Subtelny JD, Polson A. Orthodontic relapse, apical root resorption, and crestal alveolar bone levels. Am J Orthod Dentofacial Orthop 1987;91:252-8.

25. Costopoulos G, Nanda R. An evaluation of root resorption incident to orthodontic intrusion. Am J Orthod Dentofacial Orthop 1996;109:543-8.

26. Algharbi M, Bazargani F, Dimberg L. Do different maxillary expansion appliances influence the outcomes of the treatment?, European Journal of Orthodontics 2018;40:97-106.

27. Weissheimer A, de Menezes LM, Mezomo M, Dias DM, de Lima EM, Rizzatto SM. Immediate effects of rapid maxillary expansion with Haas-type and hyrax-type expanders: a randomized clinical trial. Am J Orthod Dentofacial Orthop 2011;140:366-76.