8-1-2012

Dental and Buccal Bone Stability After Rapid Maxillary Expansion and Fixed Orthodontic Treatment

Allison Milliner
Loma Linda University

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

Dental and Buccal Bone Stability After Rapid Maxillary Expansion And Fixed Orthodontic Treatment

by

Allison Milliner

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

---

August 2012

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

____, Chairperson
Kitichai Rungcharassaeng, Associate Professor of Orthodontics

____
Joseph M. Caruso, Professor of Orthodontics

____
V. Leroy Leggitt, Professor of Orthodontics

ACKNOWLEDGEMENTS

I would like to express my appreciation to the individuals who helped me complete this study. I am grateful to the Loma Linda University Department of Orthodontics and the members of my guidance committee. Thank you to Drs. Kitichai Rungcharassaeng, Joseph Caruso and Leroy Leggitt for their advice and comments.

CONTENTS

FIGURES

TABLES

ABBREVIATIONS

AE	Appliance Expansion
App	Type of Appliance
BBT	Buccal Bone Thickness
BBTT1	Initial Buccal Bone Thickness
BMBL	Buccal Marginal Bone Level
BTL	Bone Thickness Level
CBCT	Cone Beam Computed Tomography
CT	Computed Tomography
DICOM	Digital Imaging and Communications in Medicine
DifE	Differential Expansion
IA	Interdental Angle
ID	Interdental Distance
L	Left
M1	First Molar
P1	First Premolar
P2	Second Premolar
PL	Perpendicular Line
R	Right
Rate	Rate of Appliance Expansion
RL	Reference Line
RME	Rapid Maxillary Expansion
RPE	Rapid Palatal Expansion

T1	Pre-Rapid Maxillary Expansion
T2	Post-Rapid Maxillary Expansion
T3	Completion of Orthodontic Treatment
Δ BBT	Change in Buccal Bone Thickness
Δ BMBL	Change in Buccal Marginal Bone Level
Δ IA	Dental Tipping
Δ ID	Dental Expansion

ABSTRACT OF THE THESIS

Dental and Buccal Bone Stability After Rapid Maxillary Expansion And Fixed Orthodontic Treatment

by

Allison Milliner

Master of Science, Graduate Program in Orthodontics and Dentofacial Orthopedics Loma Linda University, August 2012
Dr. Kitichai Rungcharassaeng, Chairperson

The objective of this study was to quantitatively evaluate, via CBCT, the dental and osseous effects of patients who had completed comprehensive orthodontic treatment with rapid maxillary expansion (RME) in conjunction with Ricketts prescription brackets. Thirty consecutive patients (16 males, 14 females; mean age = 13.9 ± 1.9 years) who required RME as part of their orthodontic treatment and had pre-RME (T1), post-RME (T2) and final orthodontic (T3) CBCT images were included in the study. Thirteen patients had 2-banded, while 17 had 4-banded appliances.

Measurements of interdental distance (ID), interdental angle (IA), buccal bone thickness (BBT) and buccal marginal bone level (BMBL) of the first premolar (P1), second premolar (P2) and first molar (M1) at T1, T2 and T3 were made and recorded. This data was compared using Friedman, Kruskal-Wallis, Wilcoxon Signed Rank and Mann-Whitney U-tests ($\alpha = 0.05$). To determine which variables were associated with changes in ID, IA, BBT and BMBL, Kendall's Tau correlation analyses were used ($\alpha = 0.05$).

The results of this study suggest that the immediate effects of RME are uniform dental expansion from anterior to posterior, buccal crown tipping and reduction of both

BBT and BMBL. In comparison to P1 and M1, P2 exhibited more buccal crown tipping ($p = .010$) and less reduction in BBT and BMBL immediately after RME. Long term effects of RME noted in this study included greater relapse of dental expansion at M1, which led to greater overall dental expansion maintained at P1 and P2. Also of note was the bone rebound for both BBT and BMBL, on all teeth, by the end of orthodontic treatment. At T3, patients with 4-banded appliances exhibited statistically significant greater overall BBT reduction at P1 ($p = .036$) and more tipping on P2 immediately after RME ($p = .026$). Significant correlations ($p < .05$) noted in this study between the changes in BBT and BMBL at various time points indicated that vertical bone changes can be expected when there is an evidence of horizontal bone change and that the greater the initial bone reduction, the greater the bone rebounded.

CHAPTER ONE

INTRODUCTION

It has been demonstrated in the literature that approximately 21% of children have some form of transverse skeletal discrepancy.[1] Due to the high prevalence of posterior crossbite and dental crowding, rapid maxillary expansion (RME) has been a technique developed through the history of orthodontics which continues to be commonly used today as a means to resolve transverse and arch length discrepancies.

The necessity for RME can be observed through esthetics and function at evaluation. Arch length discrepancies may cause severe dental crowding, proclined incisors and an unattractive appearance of teeth. Transverse skeletal deficiency are often seen as crossbites, which ultimately can cause functional issues including restriction of maxillary and mandibular growth and trempromandibular dysfunction.[2]

Multiple studies in the past have evaluated the heavy orthopedic effect of RME on the surrounding structures. While this information was useful, cone beam computed tomography (CBCT) allows more accurate analysis of the effects of RME via three dimensional analysis.

Immediate effects of RME on the surrounding skeletal and dental structures have been identified via CBCT.[3,4] Significant findings included the reduction of both posterior buccal bone thickness and buccal marginal bone level, buccal crown tipping, dental expansion and alveolar bending. However, the CBCT evidences of the long term effect of RME on both skeletal and dental structures have not been established. In addition to the stability of the dentition, it is important to note long term findings associated with initial reduction of buccal bone thickness and level, as these parameters have been linked to periodontal problems such as bone dehiscence and gingival recession.[5]

The purpose of this study was to analyze the dental and buccal bone stability after orthodontic treatment in conjunction with RME. The null hypothesis was that there were no changes to osseous and dental parameters at the completion of orthodontic treatment when compared with immediate effects of RME, whereas, the alternative hypothesis was that there were changes noted to osseous and dental structures at the completion of orthodontic treatment when compared with measurements taken immediately after RME.

CHAPTER TWO

REVEIW OF LITERATURE

Development of the Maxilla

Formation of the maxilla occurs via intramembranous ossification and progresses in the transverse direction until just after the pubertal growth spurt. It is believed that after this time, typically between the ages of 13-15, growth at the midpalatal suture ceases and is followed by apposition until about age 15 in females and 17 in males.[5,6] As previously stated, approximately 21% of children present with some form of transverse skeletal discrepancy at the completion of this process, with no differences seen between males, females or various ethnic groups.

In many patients, it is believed that maxillary constriction develops not only by genetic factors or syndromes, but also that environmental factors such as mouth breathing and digit habits play a significant role. As shown in studies performed on rhesus monkeys, when the nasal airway was blocked and breathing inevitably had to take place through the mouth, tongue posture was affected, leading to maxillary constriction.[7] Likewise, any condition leading to habitual mouth breathing, such as allergies, can lead to posterior crossbite. Along with oral breathing, digit habits can present a disturbance in the equilibrium and may also contribute to the formation of transverse discrepancies.[8,9]

Maxillary crossbite has been associated with many unfavorable conditions, indicating the need for correction as soon as it is seen. Advantages of resolving maxillary constriction stated by Dahiya et al include elimination of dental crowding and posterior crossbite. Restriction of maxillary and mandibular growth, due to crossbites, can lead to pseudo-class III malocclusions and tempromandibular dysfunction due to a locked mandible and an altered path of closure.[2] Because of the numerous adverse effects of transverse discrepancies, many solutions for the problem have been developed through the years.

History of Rapid Maxillary Expansion

Reports of attempted maxillary expansion date as far back as 1860 with reported use of a jackscrew type appliance to separate the two maxillary halves in a fourteen year old child. Despite the fact that many believed to separate the maxillae would induce serious damage to the surrounding hard and soft tissues, multiple providers attempted expansion between the years of 1888 and 1929.[10] It was during these years the discovery was made that the two maxillae did in fact separate at the sutural level due to orthopedic forces. Previous to this, it was believed that expansion was achieved by pushing teeth through the adjacent bone.

Though there was a period of time in which maxillary expansion was not being performed in the United States, it regained popularity in the 1950's when Haas conducted a study involving pigs and confirmed the efficacy of expanding both the maxilla and nasal cavity.[11] He followed this animal study with a clinical trial on human patients in 1961. The results of his study proved the benefits of maxillary expansion in Class III malocclusions, severely constricted maxillae and patients with nasal deficiency. His findings noted that the benefits of expansion not only involved quicker treatment times due to having less movement needed with fixed appliances, but also involved creating a better equilibrium of associated muscular forces and tongue posture with an increase in nasal breathing.[10]

Over many years, expansion appliances have been improved, adjusted and refined. Haas used a tooth and tissue borne appliance that had a jackscrew in the mid-palatal region, acrylic pads on each side of the jackscrew and orthodontic bands connecting to the first premolar and first molar. Although the Haas appliance was quite effective in splitting the palatal suture, the acrylic pads induced soft tissue irritation in many patients.[10]

In an attempt to create a more hygienic appliance, Biederman created an appliance that took advantage of the effective jackscrew in the Haas appliance, but eliminated the acrylic pads.[12] The appliance, known as the Hyrax, consisted of 4 orthodontic bands connected to the first premolars and first molars with steel arms soldered to a jackscrew found in the mid-palatal region. Biederman believed this appliance to be more hygienic, easier to make and less cumbersome for patients. The Hyrax appliance has been proven to be very effective since its conception in the 1960's and continues to be routinely used today.

Skeletal and Dental Effects of Rapid Maxillary Expansion

The primary goals of RME are accomplished through bodily separation of the mid palatal suture, buccal rotation of the maxillary alveolus and buccal movement of teeth. In order to accomplish the associated orthopedic movement, a force must be applied that exceeds the limits needed for orthodontic tooth movement. It has been reported by Isaacson that between 3 and 10 pounds of pressure are produced with a single activation of a Hyrax expander, a significantly higher force than the 10-100 grams needed for various tooth movements.[13] Due to the overwhelming force of the Hyrax, physiologic changes needed to produce orthodontic movement do not have enough time to take place before the bone segments have separated, thus the effectiveness in orthopedic changes.

Orthopedic forces produced by turning the jackscrew of an expansion appliance not only act on the mid palatal suture, but also affect adjacent sutures such as the nasomaxillary, zygomaticomaxillary, zygomaticotemporal, pterygopalatine and frontomaxillary.[14] It has been reported that the resistance produced by these affected sutures explains why a pyramidal opening of the suture is noted during RME. When viewed from both the occlusal and frontal, a larger opening will be noted in the anterior region near the incisors, which progressively narrows as you travel posterior and superior.[15] An additional study completed in 2011, via CT scan, by Ghoneima et al demonstrated that of all cranial sutures affected by RME, those found more anterior were more greatly affected. These included the intermaxillary, internasal, nasomaxillary, frontomaxillary and frontonasal sutures.[16]

Along with splitting of the maxillary suture, other skeletal effects of RME can include buccal rotation of the maxillae, widening of the nasal cavity[3,17] widening of the nasal floor[18] and a lowering of the palate.[19] As one can imagine, the effect of widening the nasal cavity could be advantageous in individuals with breathing problems; however, adverse side effects to palatal expansion have been noted in certain facial types.[20] In some studies, an increase in mandibular plane angle and an opening of the bite have been noted, which would only be beneficial in brachyfacial pattern patients. In the case of openbites or vertical growth patterns, an increase of the mandibular angle or further opening of the bite would cause difficulty in achieving orthodontic treatment goals.

When determining if a patient is a good candidate for RME, facial pattern is a critical factor of consideration as well as age of the patient. It is generally agreed upon that while there is great individual variation in maturation, by age 15 for females and 18 for males, peak growth velocity has occurred and the mid palatal suture has become interdigitated with bony bridges between the two halves. Therefore, RME treatment is most effectively performed prior to the pubertal growth spurt, to prevent results of expansion shifting from the skeletal level to the dentoalveolar level.[21]

The two most common dental effects seen with RME are buccal tipping and extrusion of the teeth associated with the appliance.[22] In many studies, it has been shown that areas of decreased orthopedic palatal split show an increase in orthodontic dental tipping.[3,4,17,23] Typically, this means more dental movement will be noted in the posterior region, as well as in older patients where the suture does not split as readily as children. Extrusion will be noted due to the resultant force of the jackscrew location; this extrusion provides a dental component to the increase in vertical dimension seen with RME.

Stability of Rapid Maxillary Expansion

While many studies have looked at immediate results of RME through the use of casts, radiographs and CBCT, long term follow up of RME has primarily only been studied through casts and two dimensional radiographs. Findings in various recent studies have supported Zimring's early claims that post retention forces after RME completely dissipate after 6 weeks, consequently, RME produces orthopedically stable results.[24]

Huynh et al reported in a 2009 study of post treatment dental casts that RME cases out of treatment at least two years showed 84% of posterior crossbite correction remained with only about 33% of the initial expansion lost.[25] Similarly, Moussa performed measurements on 165 dental casts of patients out of treatment for eight to ten years and found that the maxillary arch treated with RME showed stability in the molar, canine and incisor regions.[26] Lagravere performed a systematic review of literature on both dental cast and radiograph measurements to determine the long term dental arch changes after RME. Of the four articles that met the inclusion criteria, they summarized that significant increases in molar width, canine width and arch perimeters were seen in RME patients. They also commented on the consistent finding through the literature that expansion shifts from skeletal to dentoalveolar as individuals mature past peak growth velocity.[27,28] Despite expansion changes being skeletal or dental in nature, it is consistently noted that results of RME are stable when measured through dental casts or two dimensional radiography.

Evaluation of Rapid Maxillary Expansion

Historically, assessment of the results of RME have been taken via clinical exam, photographs, dental models or two dimensional radiographs. The most common radiographs used are lateral or posteroanterior (PA) cephalograms and occlusal films. The obvious limitations of both techniques are that through photos and models, the only information provided is what can be seen clinically. In the case of two dimensional radiographs, errors are inevitable when this image is representing a three dimensional object.

Numerous studies on dental models have evaluated the changes in arch width, arch depth, molar angulation and arch perimeter.[29] While these analyses were helpful, without visualization of the roots or alveolar bone, accuracy in determining true angulation and dentoalveolar limits of tooth movement were not possible. Because the Hyrax expander is tooth borne, the exact position of teeth within the alveolar bone is essential for treatment planning and evaluating both progress and outcomes of RME treatment.

To eliminate the drawbacks of conventional two dimensional x-ray or limited data on study models, three dimensional imaging is an excellent resource to analyze the outcome of RME.[18,30] Both magnetic resonance imaging (MRI) and computed tomography (CT) have been used in the past, but both have drawbacks for routine use in orthodontics. MRI is relatively more costly and has longer acquisition times. CT delivers a higher dose of radiation versus CBCT, making it controversial for routine use in orthodontics.

In recent years, cone beam computed tomography (CBCT) has presented a suitable alternative to the drawbacks of two dimensional radiographs, MRI and traditional CT. Because the beam has a cone shape, significantly shorter image times and decreased radiation exposure are seen with CBCT.[31] In fact, it has been noted that the radiation dose given in a full mouth series of traditional dental images can be substantially higher than that of CBCT.[32] As well, the radiation dose in comparison to CT is drastically lower at 74-400mSv versus 2000-8000mSv.[32]

In addition to the benefit of lower dose radiation, accuracy in measurements from CBCT have been proven. In a study that compared linear measurements between CBCT scans and those on dry skulls, only small statistically insignificant differences were seen.[33] In fact, less than 1% error has been proven when CBCT measurements were compared with those of skulls.[34,35] In another study conducted by Timock et al on cadaver heads, accuracy between CBCT and direct measurements of buccal bone height and thickness were reported with statistically insignificant mean absolute errors of 0.30mm and 0.13mm respectively, with no bias toward over or underestimation.[36]

Because of the many benefits compared to traditional imaging and investigation, numerous providers feel that CBCT is a very practical method for craniofacial analysis in orthodontics.

CHAPTER THREE

MATERIALS AND METHODS

Patient Selection

This study was approved by the Institutional Review Board of Loma Linda University, California, USA. Thirty patients who had been treated since January 2005 at the Graduate Orthodontic Clinic, Loma Linda University School of Dentistry, and required Rapid Maxillary Expansion (RME) using Hyrax appliances as part of their comprehensive orthodontic treatment, and had the CBCT images (NewTom 3G, AFP Imaging, Elmsford, NY) before RME (T1), after RME (T2) and at orthodontic treatment completion (T3) available were included in the study. The T1 images were obtained prior to orthodontic treatment, T2 images were obtained within three months after the activation had been finalized and T3 images were taken within two months of debonding. The Hyrax appliances used were either 4-banded (supported by bilateral 1st premolars and 1st molars) [Fig. 1] or 2-banded (supported by bilateral 1st molars with expansion arms and mesial rests bonded to 1st premolars) [Fig. 2].

Figure 1. Occlusal view of 4-banded Hyrax appliance

Figure 2. Occlusal view of 2-banded Hyrax appliance

Data Collection

General information gathered from the patient's record included sex, age at the start of treatment, type of Hyrax appliance used, activation time (in weeks), retention time (in weeks, from the time of tie-off to the time the CBCT scan was performed) and removal time, which was the amount of time (in weeks) from the end of expansion until the completion of treatment and subsequent T3 CBCT scan.

Patient scans were taken in a standardized fashion having the patient in a supine position with chin and shoulder supports; a vertical sighting beam was also used to ensure their position was accurate and repeated for all three scans. Scans lasted 36 seconds and were performed at 110kV. Newton 3G Smart-Beam technology was used and based on the patient's anatomic density, milliampere values fluctuated with a maximum of 15mA delivered. Data was recorded with .2mm voxel size and was reconstructed with 0.5-mm slice thickness. The DICOM (Digital Imaging and COmmunications in Medicine) images were assessed through OsiriX Medical Imaging software v. 2.4 (Open-Source, OsiriX Medical Imaging Software: homepage.mac.com/rossetantoine/osirix/Index2.html). The following parameters were evaluated on 1st premolar (P1), 2nd premolar (P2) and 1st molar (M1) and recorded:

Buccal Marginal Bone Level (BMBL) and Bone Thickness (BBT)

From the axial section of the T1 images, at the root level of the tooth of interest (P1, P2 or M1), an opened-polygon cut was made bucco-lingually so that the root was bisected bilaterally (Fig 3). On the coronal image derived from the cut, reference lines (RL) were constructed from the buccal cusp tips to the buccal root tips bilaterally (Fig 4). A perpendicular line (PL1) to the RL was made at the most coronal point of bone contact with the tooth. The buccal marginal bone level (BMBL) was defined as the distance from PL1 to the cusp tip on the RL. A second perpendicular line (PL2) was made at the level where the buccal bone deflected. The buccal bone thickness (BBT) was the distance from the root surface to the most buccal bone surface on PL2. The distance on the RL from PL2 to the cusp tip was the bone thickness level (BTL), where the buccal bone thickness of the T2 and T3 images was measured.   This procedure was repeated for T2 and T3 measurements except that PL2 on both the T2 and T3 images were determined by the pre-RME (T1) BTL (Fig 5).   For M1, BMBL and BBT were only measured on the mesiobuccal root, as it is typically more prominent than the distobuccal area. The changes in BBT (ΔBBT) between different time points were obtained as Δ_1 (T2-T1), Δ_2 (T3-T2) and Δ_3 (T3-T1). On the other hand, the changes in BMBL (ΔBMBL) were obtained as Δ_1 (T1-T2), Δ_2 (T2-T3) and Δ_3 (T1-T3). Negative ΔBBT and ΔBMBL values signified bone loss.

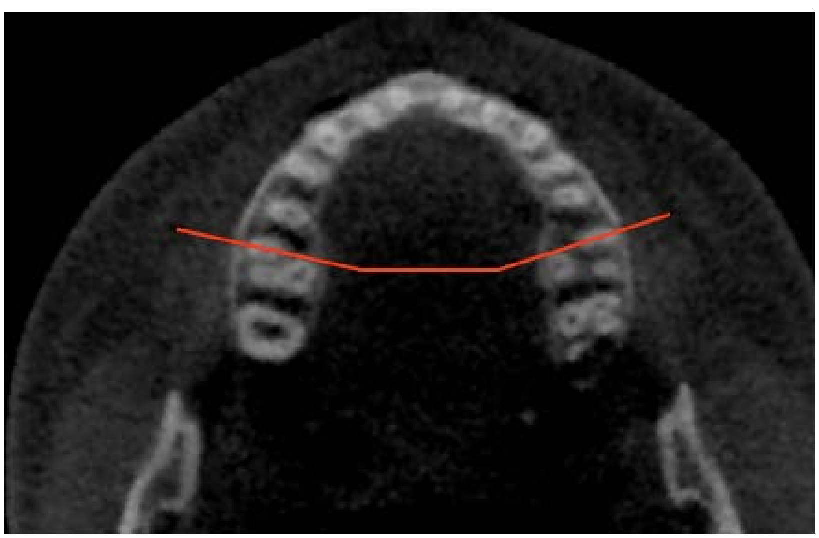

Figure 3. An opened-polygon cut was made bucco-lingually so that it bisected the mesio-buccal root of 1st molars bilaterally.

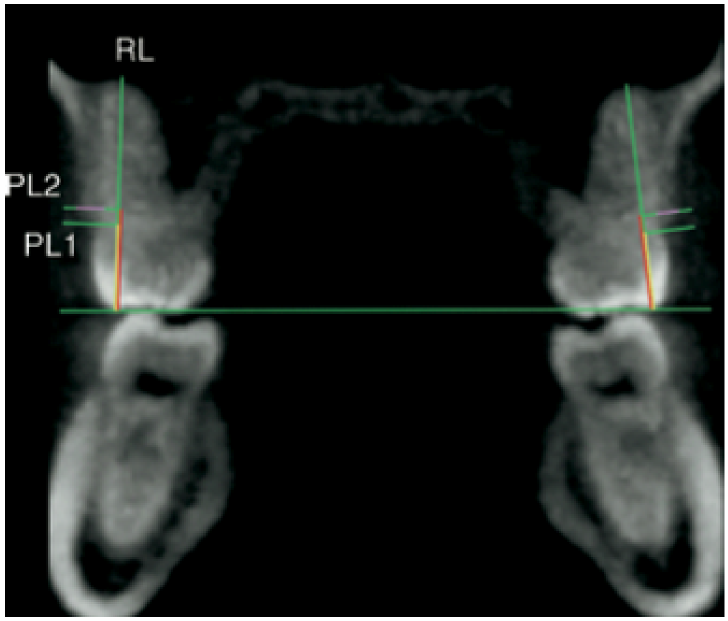

Figure 4. Pre-RME coronal image derived from the opened-polygon cut (Fig 3). RL = Reference line; PL1 = Perpendicular line 1; PL2 = Perpendicular line 2; BMBL = Buccal marginal bone level depicted in yellow; BBT = buccal bone thickness depicted in pink; BTL = Bone thickness level depicted in red.

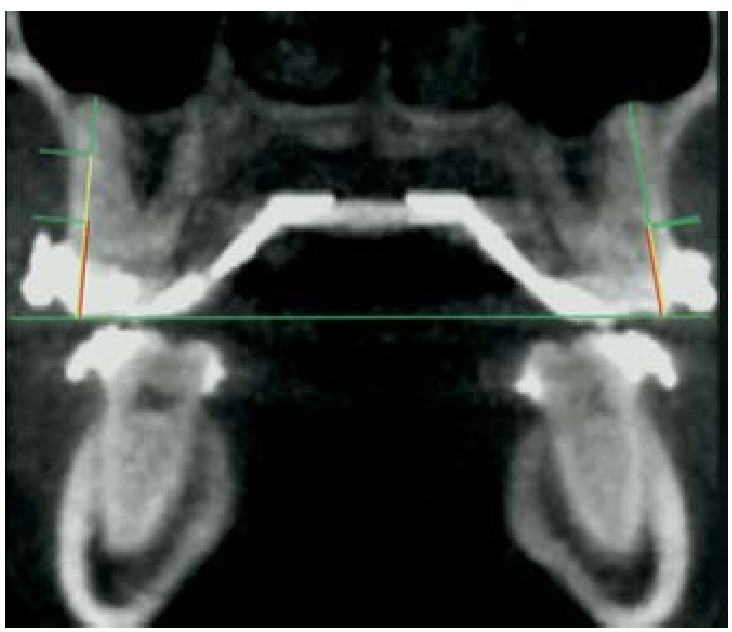

Figure 5. Post RME image. Note significant change in BMBL (yellow) and the use of BTL (red) to determine the level BBT would be measured.

Interdental Distance (ID)

From the axial section of the T1 images, at the crown level of the tooth of interest (P1, P2 or M1), an opened-polygon cut was made bucco-lingually so that it passed through the central fossae bilaterally (Fig 6). On the coronal imaged derived from the cut, an interfossal measurement was made and termed the interdental distance (ID) [Fig 7]. The procedure was repeated for T2 and T3 measurements, and their differences were the amount of dental expansion (ΔID; Δ_1 = T2-T1, Δ_2 = T3-T2 and Δ_3 = T3-T1).

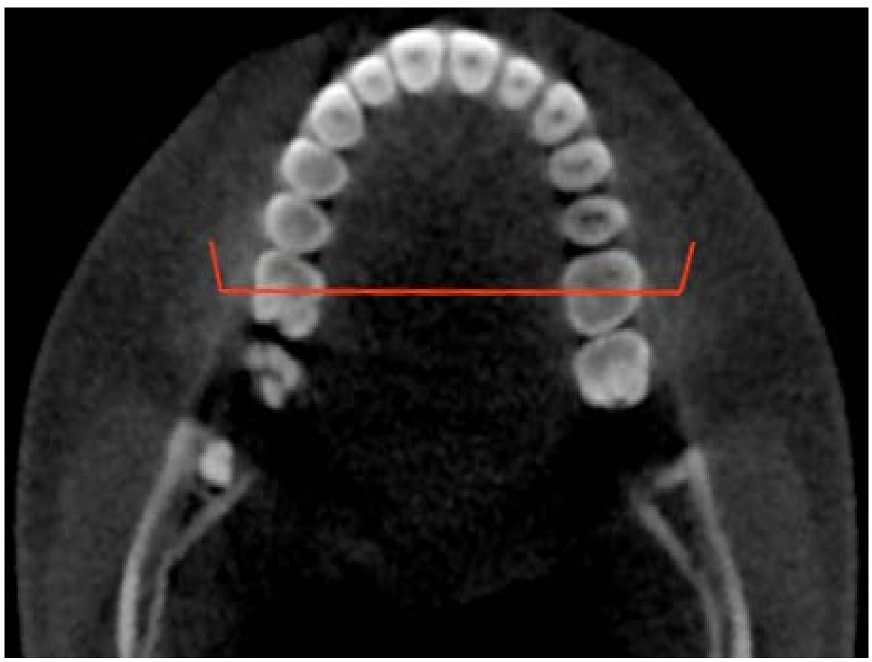

Figure 6. An opened-polygon cut was made bucco-lingually so that it passed through the central fossae of 1st molars bilaterally.

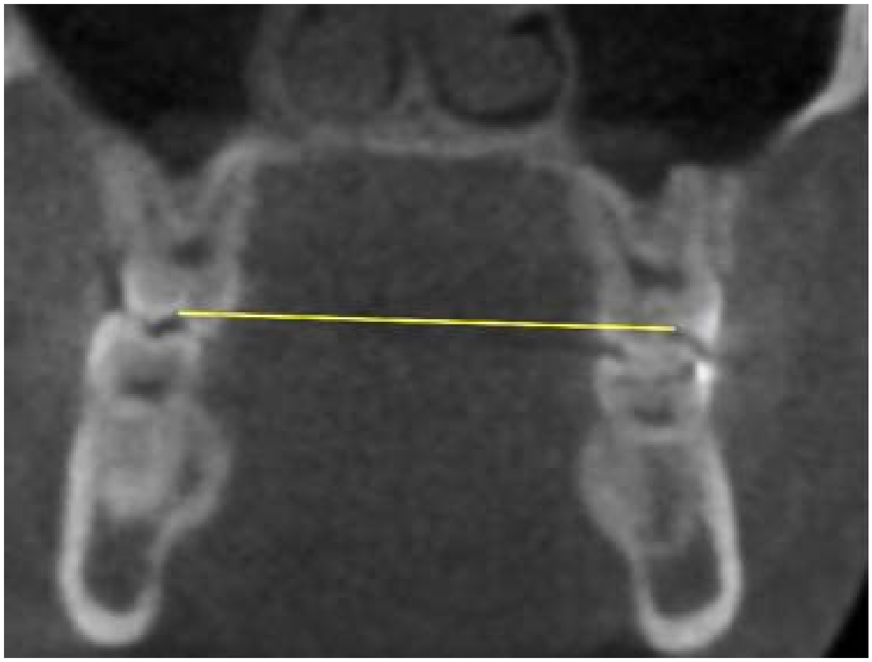

Figure 7. Coronal image derived from the opened-polygon cut (Fig 6). Inter-fossa measurement was made (yellow line), which signified inter-molar distance (ID).

Interdental Angle (IA)

From the axial section of the T1 images, at the level of the cusp tips of the tooth of interest (P1, P2 or M1), an opened-polygon cut was made bucco-lingually so that it passed through the buccal and lingual (for M1, mesiobuccal and mesiolingual) cusp tips bilaterally (Fig 8). On the coronal image derived from the cut, lines were drawn across the buccal and lingual cusp tips of both left and right teeth. The interdental angle (IA) was the angle formed by their intersection (Fig 9). This procedure was repeated for T2 and T3 images and their differences indicated the amount of dental tipping (ΔIA; Δ_1 = T2-T1, Δ_2 = T3-T2 and Δ_3 = T3-T1). A negative value represented buccal crown tipping.

Figure 8. An opened-polygon cut was made bucco-lingually so that it passed through the mesiobuccal and mesiolingual cusp tips of the 1st molars bilaterally.

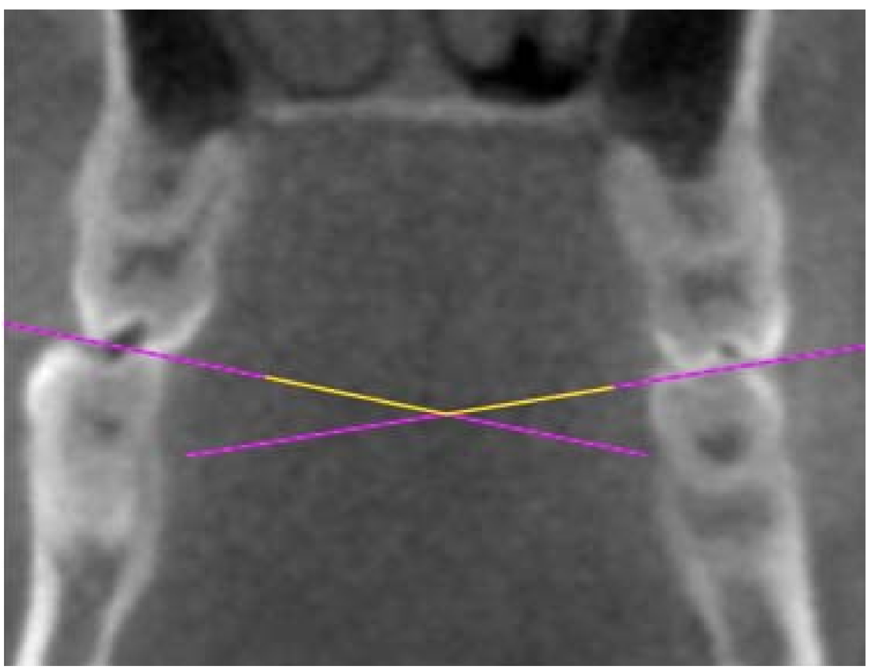

Figure 9. Coronal image derived from the opened-polygon cut (Fig 8). Inter-molar angle (IA), depicted in yellow, is the angle formed by the intersection of the lines drawn across the mesiobuccal and mesiolingual cusp tips of the 1st molars bilaterally.

Appliance Expansion (AE)

From the axial section of the post-RME images, at the level of the Hyrax appliance, an opened-polygon cut was made bisecting the appliance transversely (Fig 10). On the coronal image derived from the opened-polygon cut, the separation distance of the appliance and the thickness of the middle portion of the appliance were measured (Fig 11). Their difference signified the amount of expansion activated by the appliance.

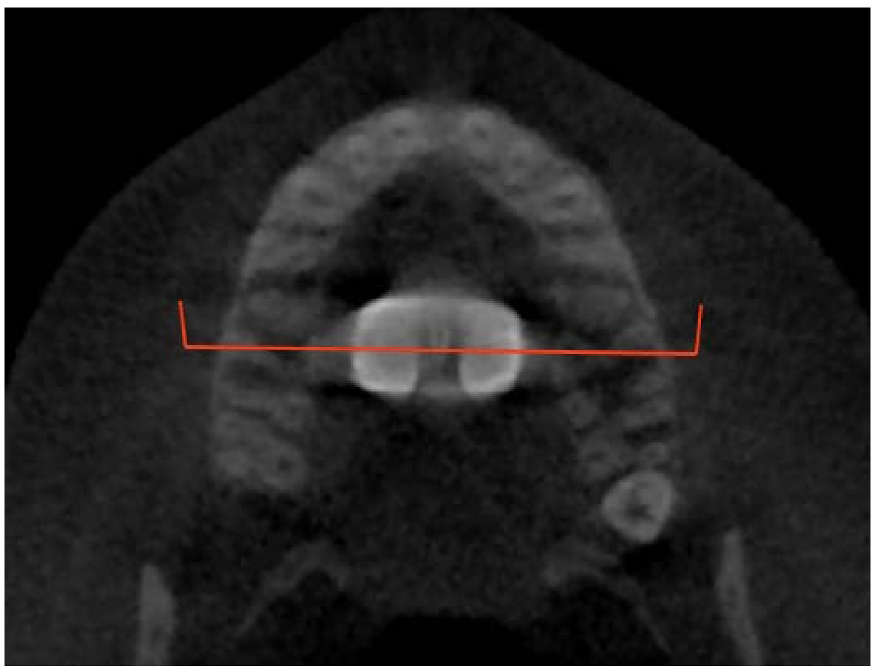

Figure 10. An opened-polygon cut was made bisecting the appliance transversely.

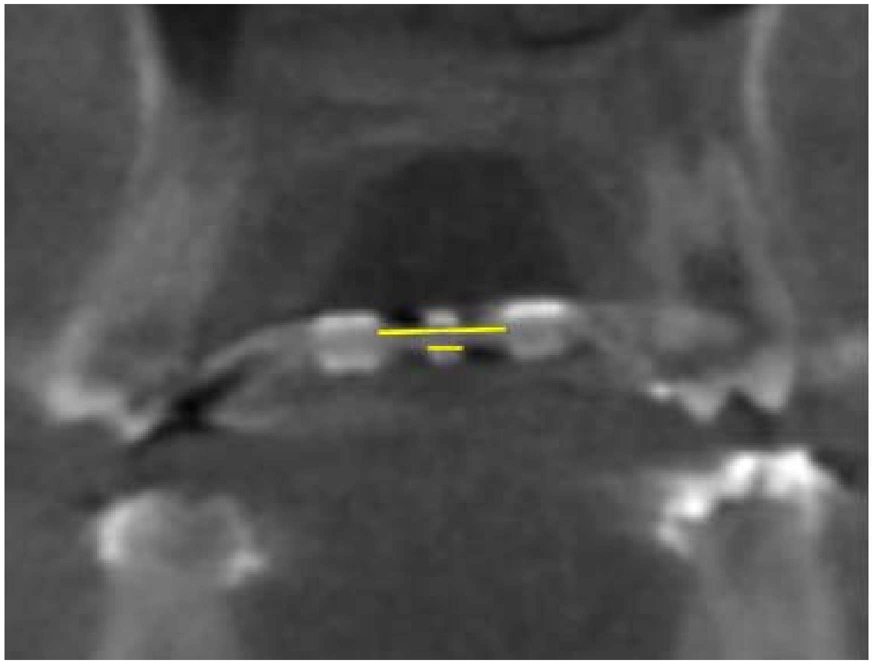

Figure 11. Coronal image derived from the opened-polygon cut (Fig 10). The appliance expansion (AE) is the difference between the separation distance of the appliance and the thickness of the middle portion of the appliance.

Rate of Appliance Expansion

Rate of appliance expansion was defined as the amount of appliance expansion divided by the activation time (mm/wk).

Differential Expansion (DifE)

Differential expansion was defined as the difference between the dental expansion after RME and the appliance expansion (Δ_1ID-AE).

Statistical Analysis

The intra-examiner reliability of the measurements was determined by using triple assessments of each parameter on M1 taken at least two weeks apart. Means and standard deviations were calculated for each parameter. Data were analyzed using Friedman, Kruskal-Wallis and Mann-Whitney U-tests. Pairwise comparisons were performed with Wilcoxon Signed Rank Tests. To determine which variables were associated with the changes in BMBL, BBT, ID and IA, Kendall's Tau correlation analyses were performed. Statistical significance was denoted when $p < .05$.

CHAPTER FOUR

RESULTS

This study included 30 patients (16 males and 14 females) with a mean age of 13.9 (range 10.3-17.8) years old. Of these 30 patients, 13 had 2-banded and 17 had 4-banded appliances. The mean appliance expansion, activation time, rate of expansion and retention time were 4.97 mm, 6.47 weeks, 1.03 mm/week and 3.93 weeks respectively (Table 1). Five patients had 1st premolar extraction during their treatment time and six patients had either unerupted or congenitally missing 2nd premolars (4 bilateral and 2 unilateral).

Table 1. Means, standard deviation and range of age, appliance expansion (AE), activation time, rate of appliance expansion, retention time and total treatment time

	Mean ± SD	Range
Age (yr)	13.9 ± 1.9	10.3 - 17.8
AE (mm)	4.97 ± 2.01	2.06 - 10.44
Activation Time (wk)	6.47 ± 4.16	2.00 - 18.00
Rate of Appliance Expansion (mm/wk)	1.03 ± 0.65	0.15 - 3.05
Retention Time (wk)	3.93 ± 4.25	0.00 - 12.00
Total Treatment Time (months)	35.12 ± 12.68	17.00 - 66.25

Measurements for the study proved to be highly reliable and reproducible based on intraclass correlation coefficients for all variables being above 0.98 (Table 2). This indicated that CBCT scans taken for this study provided images of sufficient resolution for accurate measurements.

Table 2. Intraclass Correlation Coefficients (ICC) of the variables measured on the 1st molar

Variable	ICC
BBT	0.987
BMBL	0.996
ID	0.984
IA	0.981
AE	0.998

BBT = Buccal bone thickness; BMBL = Buccal marginal bone level; ID = Interdental distance; IA = Interdental angle; AE = Appliance Expansion

Table 3 shows the means and standard deviations of all measured parameters at T1, T2 and T3. Friedman tests with pairwise Wilcoxon Signed Rank Tests were used for statistical analysis. For all parameters (ID, IA, BBT and BMBL) on P1, P2 and M1, statistically significant differences were noted between T1 and T2 ($p < .05$). When comparing T2 and T3, significant relapses were noted on all parameters except for ID P1, IA P2 and IA M1. However, only IA P1 and BMBL P2 demonstrated relapse approaching the initial values.

Table 3. Comparison of all parameters among different time intervals (T1, T2 and T3) using Friedman test at $\alpha = 0.05$

	T1 (Mean ± SD)	T2 (Mean ± SD)	T3 (Mean ± SD)	p-value
ID P1 (mm)	33.57 ± 2.56^{a}	40.65 ± 4.04^{b}	39.29 ± 2.75^{b}	.000
ID P2 (mm)	38.53 ± 3.40^{a}	44.72 ± 3.75^{b}	43.64 ± 3.40^{c}	.014
ID M1 (mm)	44.25 ± 4.05^{a}	51.08 ± 4.08^{b}	48.32 ± 3.61^{c}	.000
IA P1	195.36 ± 13.18^{a}	187.45 ± 12.14^{b}	194.04 ± 16.72^{a}	.001
IA P2	187.45 ± 12.14^{a}	168.66 ± 12.36^{b}	174.10 ± 15.72^{b}	.000
IA M1	172.48 ± 9.91^{a}	164.52 ± 11.82^{b}	168.03 ± 14.60^{b}	.012
BBT P1 (mm)	1.68 ± 0.52^{a}	0.49 ± 0.51^{b}	1.17 ± 0.63^{c}	< .001
BBT P2 (mm)	2.40 ± 0.48^{a}	1.63 ± 0.74^{b}	2.21 ± 0.67^{c}	< .001
BBT M1 (mm)	2.10 ± 0.75^{a}	0.82 ± 0.78^{b}	1.58 ± 0.70^{c}	< .001
BMBL P1 (mm)	9.88 ± 2.33^{a}	14.26 ± 3.69^{b}	11.34 ± 3.45^{c}	< .001
BMBL P2 (mm)	8.28 ± 0.82^{a}	9.28 ± 2.11^{b}	8.47 ± 0.70^{a}	.013
BMBL M1 (mm)	8.16 ± 2.17^{a}	12.49 ± 4.48^{b}	9.31 ± 2.43^{c}	< .001

a,b,c : different letters denote statistically significant difference between time intervals (Pairwise Wilcoxon Signed Rank Test at $\alpha = 0.05$)

Table 4 shows the means and standard deviations of the amount of changes of each parameter among different time intervals (Δ_1 = initial change, Δ_2 = relapse and Δ_3 = overall change). Kruskal-Wallis ranks test with pairwise Wilcoxon Signed Rank Tests were used to compare changes among different teeth. While there was no significant difference in initial dental expansion (Δ_1 ID) among all teeth (p = .35), significantly more relapse (Δ_2 ID) [p = .003] was noted on M1 resulting in its significantly less overall dental expansion Δ_3 ID (p = .000). Even though significantly greater initial dental tipping (Δ_1 IA) was observed on P2 (p = .01), the amounts of relapse (Δ_2 IA; p = .838) and overall dental tipping (Δ_3 IA; p = .055) were not significant among the teeth. Similarly, while significantly less initial bone thickness reduction (Δ_1 BBT) was observed on P2 (p

=.008), the amounts of relapse (Δ_2 BBT; p = .111) and overall bone thickness reduction (Δ_3 BBT; p = .163) were not significantly different among the teeth. Significantly less initial vertical bone reduction (Δ_1 BMBL) was observed on P2 (p = .00). Even though significantly more relapses (Δ_2 BMBL) were observed on P1 and M1 (p = .018), significantly less overall vertical bone reduction (Δ_3 BMBL) was still noted on P2 (p = .016).

Table 4. Comparison of all parameters on each tooth (P1, P2 and M1) using Kruskal-Wallis ranks test at α = 0.05

	P1 (Mean ± SD)	P2 (Mean ± SD)	M1 (Mean ± SD)	p-value
AE (mm)		4.97 ± 2.01		
DifE (mm)	2.22 ± 1.79	1.11 ± 1.96	1.86 ± 2.31	.350
Δ_1 ID (mm)	7.08 ± 2.85	6.19 ± 2.28	6.83 ± 2.73	.350
Δ_2 ID (mm)	-1.36 ± 2.99[a]	-1.08 ± 2.41[a]	-2.77 ± 2.49[b]	.003*
Δ_3 ID (mm)	5.71 ± 1.97[a]	5.11 ± 1.75[a]	4.06 ± 2.55[b]	.000*
Δ_1 IA (deg)	-7.91 ± 8.42[a]	-14.30 ± 11.27[b]	-7.96 ± 11.20[a]	.010*
Δ_2 IA (deg)	7.59 ± 13.03	5.45 ± 17.62	3.51 ± 16.82	.838
Δ_3 IA (deg)	-0.32 ± 13.75	-8.85 ± 14.09	-4.45 ± 9.60	.055
Δ_1 BBT (mm)	-1.20 ± 0.59[a]	-0.77 ± 0.69[a]	-1.28 ± 0.69[b]	.008*
Δ_2 BBT (mm)	0.68 ± 0.73	0.58 ± 0.59	0.76 ± 0.76	.111
Δ_3 BBT (mm)	-0.51 ± 0.58	-0.19 ± 0.39	-0.53 ± 0.69	.163
Δ_1 BMBL (mm)	-4.38 ± 3.43[a]	-1.01 ± 2.03[b]	-4.33 ± 4.13[a]	.000*
Δ_2 BMBL (mm)	2.92 ± 4.48[a]	0.81 ± 1.99[b]	3.19 ± 4.36[a]	.018*
Δ_3 BMBL (mm)	-1.46 ± 3.25[a]	-0.20 ± 0.58[b]	-1.15 ± 1.67[a]	.016*

a,b,c : different letters denote statistically significant difference between teeth (Pairwise Wilcoxon Signed Rank Test at α = 0.05)

Tables 5, 6 and 7 display a comparison of all parameters for 2-banded versus 4-banded appliances, using Mann-Whitney U-tests for P1, P2 and M1, respectively. For P1, 4-banded appliance displayed a significantly greater overall buccal bone thickness change (Δ_3 BBT) [Table 5; $p = .036$]. For P2, use of 4-banded appliance resulted in significantly more differential expansion ($p = .036$) and initial dental tipping (Δ_1 IA; $p = .026$) [Table 6]. For M1, there were no parameters with significant differences between the 4-banded and 2-banded appliances (Table 7).

Table 5. A comparison of 2-banded versus 4-banded appliances for P1 using Mann-Whitney U-test at $\alpha = 0.05$

	2-Banded	4-Banded	p-value
AE	5.03 ± 2.20	4.92 ± 1.92	.837
DifE	1.32 ± 1.16	2.64 ± 1.90	.075
Δ_1 ID	6.04 ± 2.33	7.56 ± 3.01	.238
Δ_2 ID	-0.53 ± 1.91	-1.76 ± 3.37	.483
Δ_3 ID	5.51 ± 1.25	5.81 ± 2.26	.549
Δ_1 IA (°)	-9.79 ± 6.33	-7.02 ± 9.28	.406
Δ_2 IA (°)	5.61 ± 11.39	8.52 ± 13.97	.263
Δ_3 IA (°)	-4.18 ± 14.93	1.50 ± 13.23	.511
Δ_1 BBT	-1.06 ± 0.59	-1.26 ± 0.60	.465
Δ_2 BBT	0.81 ± 0.69	0.62 ± 0.76	.479
Δ_3 BBT	-0.25 ± 0.45	-0.64 ± 0.61	.036*
Δ_1 BMBL	-3.61 ± 4.22	-4.74 ± 3.06	.337
Δ_2 BMBL	3.27 ± 4.00	2.76 ± 4.80	.976
Δ_3 BMBL	-0.34 ± 0.58	-1.98 ± 3.67	.223

* Statistically significant

Table 6. A comparison of 2-banded versus 4-banded appliances for P2 using Mann-Whitney U-test at $\alpha = 0.05$

	2-Banded	4-Banded	p-value
AE	5.03 ± 2.20	4.92 ± 1.92	.837
DifE	0.11 ± 2.33	1.83 ± 1.32	.036*
Δ_1 ID	5.39 ± 1.98	6.76 ± 2.38	.084
Δ_2 ID	-0.54 ± 1.94	-1.46 ± 2.70	.198
Δ_3 ID	4.85 ± 1.14	5.29 ± 2.10	.931
Δ_1 IA (°)	-9.32 ± 8.75	-17.86 ± 11.80	.026*
Δ_2 IA (°)	-1.00 ± 13.44	10.05 ± 19.22	.281
Δ_3 IA (°)	-10.32 ± 11.80	-7.81 ± 15.87	.931
Δ_1 BBT	-0.59 ± 0.57	-0.91 ± 0.76	.267
Δ_2 BBT	0.38 ± 0.55	0.72 ± 0.59	.103
Δ_3 BBT	-0.20 ± 0.42	-0.18 ±0.39	.523
Δ_1 BMBL	-0.90 ± 2.21	-1.09 ± 1.96	.426
Δ_2 BMBL	0.53 ± 2.00	1.01 ± 2.03	.259
Δ_3 BMBL	-0.36 ± 0.64	-0.08 ± 0.51	.391

* Statistically significant

Table 7. A comparison of 2-banded versus 4-banded appliances for M1 using Mann-Whitney U-test at $\alpha = 0.05$

	2-Banded	4-Banded	p-value
AE	5.03 ± 2.20	4.92 ± 1.92	.837
DifE	1.74 ± 2.77	1.95 ± 1.98	.902
Δ_1 ID	6.77 ± 3.14	6.87 ± 2.47	.711
Δ_2 ID	-2.99 ± 2.60	-2.60 ± 2.46	.711
Δ_3 ID	3.78 ± 2.45	4.28 ± 2.68	.509
Δ_1 IA (°)	-6.22 ± 10.46	-9.29 ± 11.88	.742
Δ_2 IA (°)	1.05 ± 18.87	5.39 ± 15.40	.827
Δ_3 IA (°)	-5.17 ± 11.56	-3.90 ± 8.14	.869
Δ_1 BBT	-1.14 ± 0.81	-1.39 ± 0.59	.227
Δ_2 BBT	0.89 ± 0.75	0.65 ± 0.77	.282
Δ_3 BBT	-0.25 ± 0.33	-0.74 ± 0.82	.096
Δ_1 BMBL	-2.91 ± 3.12	-5.42 ± 4.55	.103
Δ_2 BMBL	2.26 ± 3.10	3.90 ± 5.10	.420
Δ_3 BMBL	-0.65 ± 0.98	-1.52 ± 2.00	.310

* Statistically significant

Tables 8-10 demonstrate Kendall's Tau (τ) correlation coefficients and respective p-values for changes in P1, P2 and M1. Gender, age and rate of expansion did not demonstrate any significant correlation to the overall dental and buccal bone changes (Δ_3) for P1, P2 or M1. This was noted on Tables 8-10 with p □ .05 for all respective variables.

The amount of appliance expansion, while correlated to some changes in ID and IA in all teeth involved ($p < .05$), was not correlated (p □ .05) to the buccal bone changes (BBT or BMBL for all Δ_1, Δ_2 or Δ_3) for any of the teeth, as seen in Tables 8-10.

Initial buccal bone thickness (BBTT1) demonstrated only one correlation to all bone changes associated with RME, which was a negative correlation with overall horizontal bone reduction (Δ_3 BBT) for M1 [$\tau = -0.357$, $p = .006$; Table 10].

Positive correlations between Δ_1 BMBL and Δ_1 BBT, and negative correlations to their respective Δ_2 were seen for all teeth ($p < .05$; Tables 8-10). Except for P2, overall changes in buccal bone height and thickness (Δ_3 BMBL and Δ_3 BBT) in both P1 and M1 were also correlated to each other ($p < .05$; Tables 8 and 10).

Table 8. Matrix of Kendall's Tau correlation coefficient for changes in maxillary 1st premolar

	Gender	Age	AE	RT	Rate	App	Δ_1 ID	Δ_1 IA	Δ_1 BMBL	Δ_1 BBT	Δ_2 ID	Δ_2 IA	Δ_2 BMBL	Δ_2 BBT	Δ_3 ID	Δ_3 IA	Δ_3 BMBL	Δ_3 BBT	BTT1	DifE	TTT	T3-T2
Gender	r =1.000 p =																					
Age	-0.232 0.134	1.000																				
AE	-0.276 0.074	0.233 0.071	1.000																			
RT	-0.042 0.787	-0.125 0.335	0.065 0.617	1.000																		
Rate	0.125 0.418	0.250 0.054	0.253* 0.050	-0.270* 0.037	1.000																	
App	0.009 0.961	0.240 0.121	0.035 0.818	-0.246 0.112	0.145 0.346	1.000																
Δ_1 ID	-0.314 0.064	0.298* 0.037	0.660** 0.000	-0.023 0.870	0.247 0.084	0.208 0.221	1.000															
Δ_1 IA	0.287 0.092	-0.171 0.233	-0.220 0.123	0.010 0.944	-0.047 0.744	0.149 0.382	-0.307* 0.032	1.000														
Δ_1 BMBL	0.045 0.771	-0.264* 0.043	-0.123 0.343	0.075 0.567	-0.028 0.830	-0.388* 0.013	-0.193 0.176	0.180 0.207	1.000													
Δ_1 BBT	0.305 0.073	-0.271 0.058	-0.200 0.161	-0.043 0.761	0.053 0.709	-0.129 0.449	-0.273 0.055	0.153 0.283	0.573** 0.000	1.000												
Δ_2 ID	0.143 0.359	-0.171 0.191	-0.565** 0.000	0.126 0.334	-0.251 0.053	-0.114 0.463	-0.620** 0.000	0.260 0.069	0.167 0.203	0.213 0.135	1.000											
Δ_2 IA	-0.026 0.868	0.016 0.900	0.165 0.204	0.033 0.802	0.172 0.186	0.179 0.249	0.260 0.069	-0.167 0.243	-0.073 0.578	-0.053 0.709	-0.369** 0.005	1.000										
Δ_2 BMBL	0.110 0.479	0.208 0.111	0.040 0.761	-0.093 0.474	-0.028 0.830	0.108 0.489	0.053 0.709	-0.147 0.304	-0.642** 0.000	-0.353* 0.013	-0.111 0.399	0.082 0.530	1.000									
Δ_2 BBT	-0.099 0.530	0.254 0.054	0.172 0.190	0.033 0.801	-0.061 0.640	0.146 0.354	0.201 0.161	-0.140 0.326	-0.470** 0.000	-0.542** 0.000	-0.208 0.117	0.174 0.188	0.613** 0.000	1.000								
Δ_3 ID	-0.287 0.092	0.157 0.272	0.067 0.640	0.023 0.870	-0.067 0.640	0.109 0.522	0.220 0.123	-0.180 0.207	0.040 0.779	-0.067 0.640	0.160 0.262	-0.173 0.225	-0.180 0.207	-0.054 0.708	1.000							
Δ_3 IA	0.129 0.446	-0.198 0.168	-0.198 0.168	-0.010 0.944	0.160 0.262	0.119 0.485	0.073 0.607	0.313* 0.028	0.213 0.135	0.040 0.779	-0.120 0.400	0.520** 0.000	-0.153 0.283	0.060 0.674	-0.187 0.191	1.000						
Δ_3 BMBL	0.266 0.088	-0.112 0.390	-0.126 0.334	0.086 0.508	0.035 0.788	-0.353* 0.023	-0.290* 0.042	0.050 0.726	0.264* 0.045	0.264 0.065	0.207 0.114	-0.170 0.197	0.094 0.473	0.048 0.719	-0.177 0.216	-0.030 0.833	1.000					
Δ_3 BBT	0.143 0.359	-0.077 0.555	-0.077 0.555	0.075 0.567	0.140 0.283	-0.375* 0.016	0.087 0.544	-0.060 0.674	0.153 0.244	0.040 0.779	-0.087 0.507	-0.148 0.258	0.139 0.290	0.193 0.144	-0.173 0.225	0.080 0.575	0.509** 0.000	1.000				
BBTT1	-0.488** 0.005	0.261 0.053	0.122 0.363	0.104 0.441	-0.140 0.295	0.011 0.944	0.160 0.262	-0.080 0.575	-0.024 0.859	0.158 0.242	-0.125 0.353	0.231 0.085	-0.072 0.593	-0.247 0.006	0.087 0.544	0.113 0.427	-0.128 0.343	-0.123 0.362	1.000			
DifE	-0.388* 0.022	0.245 0.088	0.140 0.327	-0.204 0.154	0.020 0.889	0.307 0.071	0.480** 0.001	-0.267 0.062	-0.073 0.607	-0.193 0.176	-0.233 0.102	0.180 0.207	-0.080 0.575	0.040 0.779	0.353* 0.013	-0.047 0.744	-0.290* 0.042	-0.167 0.243	0.187 0.191	1.000		
TTT	-0.042 0.787	-0.125 0.335	0.065 0.617	1.000**	-0.270* 0.037	-0.246 0.112	-0.023 0.870	0.020 0.944	0.075 0.567	-0.043 0.761	0.126 0.334	0.033 0.802	-0.093 0.474	0.033 0.801	0.023 0.870	-0.010 0.944	0.086 0.508	0.075 0.567	0.104 0.441	-0.204 0.154	1.000	
T3-T2	-0.096 0.533	-0.155 0.232	0.025 0.844	0.865** 0.000	-0.272* 0.035	-0.184 0.233	-0.070 0.624	0.063 0.657	0.156 0.231	0.057 0.691	0.193 0.137	0.016 0.900	-0.184 0.157	-0.059 0.653	0.017 0.907	0.050 0.726	0.098 0.452	0.049 0.707	0.119 0.374	-0.150 0.293	0.865** 0.000	1.000

Table 9. Matrix of Kendall's Tau correlation coefficient for changes in maxillary 2nd premolar

	Gender	Age	AE	RT	Rate	App	Δ_1 ID	Δ_1 IA	Δ_1 BMBL	Δ_1 BBT	Δ_2 ID	Δ_2 IA	Δ_2 BMBL	Δ_2 BBT	Δ_3 ID	Δ_3 IA	Δ_3 BMBL	Δ_3 BBT	BTT1	DifE	TTT	T3-T2
Gender	r =1.000 p =																					
Age	-0.232 0.134	1.000																				
AE	-0.276 0.074	0.233 0.071	1.000																			
RT	-0.042 0.787	-0.125 0.335	0.065 0.617	1.000																		
Rate	0.125 0.418	0.250 0.054	0.253* 0.050	-0.270* 0.037	1.000																	
App	0.009 0.961	0.240 0.121	0.035 0.818	-0.246 0.112	0.145 0.346	1.000																
Δ_1 ID	-0.242 0.164	0.244 0.096	0.461** 0.002	0.022 0.882	0.033 0.823	0.301 0.084	1.000															
Δ_1 IA	0.035 0.839	-0.320* 0.029	-0.014 0.921	0.157 0.286	-0.051 0.728	-0.387* 0.026	-0.250 0.087	1.000														
Δ_1 BMBL	0.003 0.983	-0.465** 0.000	-0.075 0.566	0.106 0.420	-0.288* 0.027	-0.184 0.239	-0.098 0.503	0.290* 0.047	1.000													
Δ_1 BBT	0.068 0.661	-0.268* 0.041	0.000 1.000	0.059 0.654	-0.059 0.654	-0.092 0.556	-0.047 0.747	0.217 0.137	0.476** 0.000	1.000												
Δ_2 ID	-0.069 0.661	-0.144 0.274	-0.283* 0.030	0.165 0.209	-0.178 0.173	-0.207 0.186	-0.604** 0.000	0.243 0.096	0.093 0.483	0.041 0.760	1.000											
Δ_2 IA	-0.101 0.518	0.108 0.409	0.407** 0.002	0.007 0.957	0.157 0.230	0.171 0.275	0.541** 0.000	-0.254 0.083	-0.110 0.408	-0.043 0.746	0.389** 0.003	1.000										
Δ_2 BMBL	-0.061 0.693	0.533** 0.000	0.095 0.464	-0.060 0.642	0.273* 0.035	0.159 0.305	0.062 0.673	-0.239 0.102	-0.815** 0.000	-0.448** 0.001	-0.017 0.900	0.057 0.667	1.000									
Δ_2 BBT	-0.052 0.739	0.373** 0.004	0.009 0.943	-0.070 0.592	0.049 0.707	0.221 0.154	0.233 0.112	-0.338* 0.021	-0.535** 0.000	-0.630** 0.000	-0.165 0.209	0.012 0.928	0.513** 0.000	1.000								
Δ_3 ID	-0.328 0.060	0.266 0.070	0.192 0.188	0.263 0.074	-0.149 0.309	0.015 0.930	0.204 0.165	-0.004 0.980	-0.004 0.980	-0.070 0.636	0.196 0.180	0.018 0.901	0.171 0.244	0.269 0.066	1.000							
Δ_3 IA	-0.136 0.434	-0.080 0.585	0.362* 0.013	0.106 0.472	0.123 0.399	0.020 0.907	0.345* 0.018	0.130 0.372	0.043 0.766	0.087 0.552	-0.221 0.130	0.616** 0.000	-0.051 0.728	-0.091 0.535	0.069 0.637	1.000						
Δ_3 BMBL	-0.134 0.392	0.128 0.333	0.146 0.266	0.144 0.274	-0.073 0.578	0.023 0.883	0.157 0.285	-0.088 0.551	0.053 0.692	-0.005 0.971	0.141 0.288	0.167 0.207	0.123 0.350	0.016 0.900	0.074 0.619	-0.128 0.384	1.000					
Δ_3 BBT	0.134 0.392	0.052 0.693	-0.122 0.351	-0.002 0.986	-0.171 0.191	0.046 0.769	0.083 0.568	-0.130 0.372	-0.019 0.885	0.314* 0.017	-0.036 0.787	-0.176 0.183	0.024 0.858	0.050 0.706	-0.033 0.823	-0.174 0.234	-0.033 0.801	1.000				
BBTT1	-0.045 0.771	0.166 0.204	0.072 0.580	-0.094 0.500	-0.028 0.830	0.059 0.706	0.262 0.074	-0.163 0.264	-0.059 0.654	-0.371** 0.005	-0.203 0.123	0.191 0.146	0.091 0.485	0.323* 0.014	0.262 0.074	0.113 0.442	-0.007 0.957	-0.168 0.202	1.000			
DifE	-0.035 0.839	0.095 0.519	-0.116 0.427	-0.179 0.224	-0.080 0.585	0.356* 0.040	0.425** 0.004	-0.348* 0.017	-0.072 0.620	-0.116 0.427	-0.345* 0.018	0.196 0.180	0.007 0.960	0.279 0.056	0.054 0.710	0.029 0.843	-0.022 0.882	0.246 0.092	0.316* 0.031	1.000		
TTT	-0.042 0.787	-0.125 0.335	0.065 0.617	1.000**	-0.270* 0.037	-0.246 0.112	0.022 0.882	0.157 0.286	0.106 0.420	0.059 0.654	0.165 0.209	0.007 0.957	-0.060 0.642	-0.070 0.592	0.263 0.074	0.106 0.472	0.144 0.274	-0.002 0.986	-0.009 0.943	-0.179 0.224	1.000	
T3-T2	-0.096 0.533	-0.155 0.232	0.025 0.844	0.865** 0.000	-0.272* 0.035	-0.184 0.233	-0.029 0.843	0.083 0.568	0.157 0.230	0.063 0.628	0.230 0.079	-0.040 0.761	-0.102 0.432	-0.123 0.343	0.233 0.112	0.047 0.747	0.087 0.507	-0.059 0.654	-0.023 0.858	-0.171 0.244	0.865** 0.000	1.000

Table 10. Matrix of Kendall's Tau correlation coefficient for changes in maxillary 1st molar

	Gender	Age	AE	RT	Rate	App	Δ_1 ID	Δ_1 IA	Δ_1 BMBL	Δ_1 BBT	Δ_2 ID	Δ_2 IA	Δ_2 BMBL	Δ_2 BBT	Δ_3 ID	Δ_3 IA	Δ_3 BMBL	Δ_3 BBT	BTT1	DifE	TTT	T3-T2
Gender	r =1.000 p =																					
Age	-0.232 0.134	1.000																				
AE	-0.276 0.074	0.337 0.069	1.000																			
RT	-0.042 0.787	-0.198 0.295	0.183 0.333	1.000																		
Rate	0.125 0.418	0.306 0.100	0.207 0.272	-0.481** 0.007	1.000																	
App	0.009 0.961	0.247 0.188	-0.026 0.890	-0.299 0.109	0.141 0.456	1.000																
Δ_1 ID	-0.131 0.394	0.097 0.453	0.364** 0.005	0.215 0.097	0.131 0.309	0.065 0.676	1.000															
Δ_1 IA	0.282 0.067	-0.256* 0.048	-0.375** 0.004	-0.088 0.498	-0.285* 0.027	-0.055 0.722	-0.359** 0.005	1.000														
Δ_1 BMBL	-0.038 0.803	-0.048 0.708	-0.002 0.986	0.157 0.225	0.037 0.775	-0.255 0.098	0.014 0.915	-0.034 0.789	1.000													
Δ_1 BBT	-0.090 0.561	0.005 0.972	0.028 0.830	0.081 0.532	0.058 0.655	-0.174 0.258	0.062 0.630	0.009 0.943	0.446** 0.001	1.000												
Δ_2 ID	-0.032 0.835	-0.053 0.681	-0.186 0.148	0.018 0.886	-0.170 0.187	0.061 0.691	-0.391** 0.002	0.379** 0.003	0.080 0.532	-0.069 0.592	1.000											
Δ_2 IA	-0.141 0.360	0.298* 0.021	0.384** 0.003	-0.042 0.748	0.239 0.063	0.035 0.818	0.285* 0.027	-0.669** 0.000	-0.002 0.986	-0.037 0.775	-0.416** 0.001	1.000										
Δ_2 BMBL	-0.032 0.835	0.002 0.986	0.108 0.402	-0.148 0.253	0.060 0.643	0.087 0.572	0.000 1.000	-0.053 0.682	-0.591** 0.000	-0.285* 0.027	-0.186 0.148	0.154 0.232	1.000									
Δ_2 BBT	0.103 0.506	-0.266* 0.040	-0.090 0.487	0.005 0.972	-0.101 0.432	-0.145 0.346	0.051 0.695	0.053 0.682	-0.467** 0.000	-0.442** 0.001	-0.200 0.121	-0.016 0.901	0.526** 0.000	1.000								
Δ_3 ID	-0.179 0.244	0.039 0.762	0.126 0.326	0.240 0.063	-0.023 0.858	0.106 0.490	0.364** 0.005	-0.044 0.735	0.117 0.363	-0.087 0.498	0.246 0.056	-0.067 0.605	-0.205 0.112	-0.117 0.363	1.000							
Δ_3 IA	0.096 0.533	0.242 0.061	0.274* 0.034	-0.152 0.239	0.087 0.498	0.029 0.851	0.239 0.063	-0.246 0.056	-0.094 0.464	-0.074 0.568	-0.306* 0.018	0.577** 0.000	0.172 0.181	-0.117 0.363	-0.076 0.556	1.000						
Δ_3 BMBL	-0.067 0.662	0.079 0.544	0.129 0.318	0.016 0.901	0.099 0.443	-0.142 0.357	-0.002 0.986	-0.124 0.335	0.110 0.392	0.122 0.344	-0.203 0.116	0.161 0.212	0.299* 0.020	0.138 0.284	-0.203 0.116	0.078 0.544	1.000					
Δ_3 BBT	-0.055 0.724	-0.079 0.544	0.120 0.353	0.113 0.382	0.062 0.630	-0.245 0.112	0.182 0.159	-0.018 0.886	-0.101 0.432	0.274* 0.034	-0.281* 0.029	-0.009 0.943	-0.262* 0.042	0.285* 0.027	-0.147 0.253	-0.046 0.721	0.289** 0.003	1.000				
BBTT1	-0.064 0.678	0.042 0.748	-0.005 0.972	0.021 0.881	0.002 0.986	-0.032 0.834	0.007 0.957	-0.064 0.617	0.258* 0.046	-0.251 0.052	0.143 0.269	0.018 0.886	-0.235 0.069	-0.101 0.432	0.212 0.101	-0.037 0.775	-0.012 0.929	-0.357* 0.006	1.000			
DifE	0.109 0.480	-0.109 0.401	-0.182 0.159	0.175 0.175	-0.060 0.643	0.023 0.884	0.456** 0.000	-0.011 0.929	-0.090 0.487	-0.014 0.915	-0.218 0.090	0.002 0.986	0.021 0.872	0.200 0.121	0.297* 0.021	0.002 0.986	-0.166 0.199	0.129 0.318	-0.060 0.643	1.000		
TTT	-0.042 0.787	-0.125 0.335	0.065 0.617	1.000	-0.270* 0.037	-0.246 0.112	0.215 0.097	-0.088 0.498	0.157 0.225	0.081 0.532	0.018 0.886	-0.042 0.748	-0.148 0.253	0.005 0.972	0.240 0.063	-0.152 0.239	0.016 0.901	0.113 0.382	0.169 0.192	0.175 0.175	1.000	
T3-T2	-0.096 0.533	-0.155 0.232	0.025 0.844	0.865** 0.000	-0.272* 0.035	-0.184 0.233	0.152 0.239	-0.044 0.735	0.094 0.464	-0.005 0.972	0.071 0.580	-0.113 0.382	-0.108 0.402	0.053 0.681	0.247 0.056	-0.233 0.071	-0.030 0.817	0.074 0.568	0.152 0.239	0.127 0.326	0.865** 0.000	1.000

CHAPTER FIVE

DISCUSSION

Previous studies have concluded that in addition to dental expansion, immediate effects of RME have also included dental tipping, decreased alveolar bone height and decreased bone thickness.[3-5] The results of this study demonstrated similar results with statistically significant dental expansion (change in ID), buccal crown tipping (change in IA), reduction in buccal marginal bone level (change in BMBL) and reduction of buccal bone thickness (change in BBT) with respect to maxillary posterior teeth (T1 vs. T2; $p < .05$; Table 3). The fact that most parameters experienced a significant relapse after orthodontic treatment (T2 vs. T3; Table 3) suggests that the immediate effects of RME; especially where buccal bone is involved; while seem detrimental, are transient and reversible.

While there were no significant differences in immediate dental expansion (Δ_1 ID) among P1, P2 and M1 ($p = .350$; Table 4), M1 experienced greater relapse (Δ_2 ID) [$p = .003$; Table 4]. This resulted in the least overall dental expansion (Δ_3 ID) observed in M1 ($p = .000$; Table 4). Therefore, although this study found dental expansion to be parallel from anterior to posterior, the amount of expansion that remained at orthodontic completion was greater in the anterior versus posterior.

Even though significantly greater initial dental tipping (Δ_1 IA) was observed on P2 ($p = .01$), the amounts of relapse (Δ_2 IA; $p = .838$) were not significant among the teeth (Table 4). This resulted in greater overall dental tipping observed in P2; however, these differences were not statistically significant (Δ_3 IA; $p = .055$; Table 4). The greater tipping on P2 was likely due to a moment of force placed on the teeth not having rigid attachments to the expander which likely encouraged tipping versus bodily movement.[3,4,18]

Statistically significantly less buccal bone reduction was noted in both horizontal (BBT) and vertical (BMBL) dimensions for P2 immediately after expansion (Δ_1; $p < .05$; Table 4). This was likely due to the lack of direct attachment of P2 to the expansion appliance.[3,37] For changes in BBT, the amounts of bone gain (Δ_2 BBT; $p = .111$) were not significant among the teeth (Table 4), which resulted in less overall horizontal bone reduction observed in P2 (Table 4). However, these differences were not statistically significant (Δ_3 BBT; $p = .163$; Table 4). The results of this study indicated that an average of 0.51 mm, 0.19 mm and 0.53 mm of buccal horizontal bone reduction on P1, P2 and M1 respectively, could be expected after fixed orthodontic treatment in conjunction with RME. These represent 30% (P1), 8% (P2) and 25% (M1) of their original bone thickness.

For changes in BMBL, despite the fact that less bone gain was observed on P2 (Δ_2 BMBL; $p = .018$), the overall vertical bone reduction observed in P2 was still less than P1 and M1 (Δ_3 BMBL; $p = .016$; Table 4). The results of this study indicated that an average of 1.46 mm, 0.20 mm and 1.15 mm of buccal vertical bone reduction on P1, P2 and M1 respectively, could be expected after fixed orthodontic treatment in conjunction with RME. The recovery of buccal marginal bone level and thickness found in this study via CBCT is in accordance with the CT results reported by Ballanti et al.[38] This is encouraging when contemplating the long term effects to buccal bone in response to RME and orthodontic treatment.

The results of this study showed that 4-banded appliances resulted in greater overall horizontal and vertical bone reduction in P1 and M1. However, the only statistically significant difference observed was in the overall horizontal bone reduction on P1 (Δ_3 BBT; p = .036; Table 5). Greater overall horizontal (Δ_3 BBT) and vertical (Δ_3 BMBL) bone reduction was also shown to be associated with the 4-banded appliance in only P1 (Tables 8-10). This could indicate that either banded attachments to teeth during expansion may be associated with overall increased bone reduction or bonded attachments may potentially allow greater bone regeneration. These findings were consistent with a prior study conducted by Davidovitch et al in which greater dental and skeletal effects were noted on patients with 4-banded versus 2-banded appliances.[23]

Gender, age and rate of expansion did not demonstrate any significant correlation to the overall dental and buccal bone changes in all teeth (Δ_3; Tables 8-10). This implies that the dental and buccal bone effects of RME are consistent in adolescent patients regardless of age and gender. When compared to rapid expansion (0.2 - 0.5 mm/day), slow expansion (0.4 - 1.1 mm/week) has been reported to produce less tissue resistance and better bone formation in the intermaxillary suture, which helped minimize post-expansion relapse.[39] However, the results of this study show that, with respect to stability of dental and buccal bone changes, the rate of appliance expansion does not seem to have any long term effects.

It is interesting to note that the amount of appliance expansion, while was correlated to changes in ID and IA in all teeth involved, was not correlated to the buccal bone changes in any of the teeth (Tables 8-10). These results suggested that in orthodontic treatment with RME, regardless of the amount of appliance expansion, certain amount of vertical and horizontal buccal bone reduction could be expected at the completion of the treatment.

The only overall change correlated to the initial buccal bone thickness (BBTT1) was the horizontal bone reduction (Δ_3 BBT) in M1 (Table 10). It is worthwhile to note that this is a negative correlation ($\tau = -0.357$, $p = .006$; Table 10), which means the thicker the BBTT1, the greater horizontal bone reduction could be expected.

Positive correlations between Δ_1 BMBL and Δ_1 BBT, and the negative correlations to their respective Δ_2 in all teeth ($p < .05$; Tables 8-10) indicated that vertical bone reduction can be attributed to the horizontal bone reduction and vice versa, and that the greater the initial bone loss, the greater is the bone rebound. Except for P2, Δ_3 BMBL and Δ_3 BBT in both P1 and M1 were also correlated to each other.

When assessing resulting data from this study, several factors must be considered in regards to image quality of the CBCT. Voxel size, noise, scatter, artifacts and bone density all affect the quality of the image and therefore the capability to record accurate measurements. The effects of these parameters on this study will be discussed below.

The voxel size used for this study was 0.2mm, which has been reported to produce approximately 0.4mm spatial resolution, which is defined as the scan's ability to differentiate between two objects within close proximity.[40] While the most effective way to increase the resolution is to decrease the voxel size, the trade off is that the image becomes more sensitive to noise with smaller voxel sizes.[41] Noise is mainly caused by scattered radiation in a CBCT scan[42] and the larger the field of view, the greater the scatter radiation. While this study had favorable voxel size, one of the limitations in image quality was the large field of view that created a greater sensitivity to noise from scatter, thus also negatively affecting the spatial resolution.

A second factor affecting image quality of this study, and potentially buccal bone measurements, were metal artifacts. Streaking artifacts left from metal expanders and brackets, such as those present in our T2 images, have been shown to affect how a scanner interprets and reconstructs surrounding structures.[43] The voxel's perceived density of structures adjacent to an expander likely compromised spatial resolution[44], and thus, buccal bone measurements.

Lastly, another factor to consider with respect to accuracy of buccal bone measurements in this study was recent orthodontic tooth movement. It has been shown that as force is applied to a tooth to induce orthodontic movement, the resulting osteoclastic activity and bone turnover causes a decrease in bone density.[45] Since a CBCT scan distinguishes different matters through through their difference in density, it is difficult to identify the less dense immature bone on the CBCT image.[46] Therefore, waiting at least one year before taking a final scan has been recommended for buccal bone measurement.[46]

There have been various studies conducted in the past that look at immediate effects of RME. Initially they were performed on casts and radiographs, but now numerous studies have been conducted with CBCT. However, there are still very few studies that have examined the long term effects of RME with CBCT. Because this study is one of the first of its kind, future studies with larger sample sizes, longer retention periods or smaller fields of view in the images will provide additional insight into the lasting effects, if any, of RME.

CHAPTER FIVE

CONCLUSIONS

Within the confine of this study, the following conclusions could be made:

1. Immediate effects of RME include buccal crown tipping, reduction of BBT and BMBL for P1, P2 and M1.
2. Bone is regained after expansion in both horizontal and vertical directions; total horizontal bone reduction expected at the completion of orthodontic treatment is.51, .19 and .53mm and total vertical bone reduction expected is 1.46, .20 and 1.15mm for P1, P2 and M1 respectively.
3. Overall dental expansion was greater in the anterior versus posterior for P1, P2 and M1.
4. P2 exhitibed significantly more tipping but less horizontal and vertical bone reduction in response to RME when compared with P1 or M1.
5. Changes in BBT and BMBL were significantly related to each other for all teeth involved at Δ_1, Δ_2 and Δ_3.
6. Four-banded appliances showed significantly greater overall reduction of BBT versus 2-banded for P1.
7. At the completion of orthodontic treatment, when comparing P1, P2 and M1, significant relapse in dental expansion was noted for M1, while no significant differences in relapse of tipping were noted between the teeth.

8. Initial buccal bone thickness (BBTT1) showed correlation to overall horizontal bone reduction for M1 only.

REFERENCES

1. da Silva Filho OG, Santamaria M, Jrl, Capelozza Filho L. Epidemiology of posterior crossbite in the primary dentition. J Clin Pediatr Dent 2007;32:73-78.

2. Dahiya A, Maheshwari S, Gupta ND, Goyal S, Rohtak. Maxillary expansion - an interceptive modality in mixed dentition. J Indian Soc Pedo Prev Dent 1999;18:1:24-28.

3. Rungcharassaeng K, Caruso JM, Kan JY, Kim J, Taylor GD. Factors affecting buccal bone changes of maxillary posterior teeth after rapid maxillary expansion. Am J Orthod Dentofacial Orthop 2007;132:428.e1-428.e8.

4. Garrett BJ, Caruso JM, Rungcharassaeng K, Farrage JR, Kim JS, Taylor GD. Skeletal effects to the maxilla after rapid maxillary expansion assessed with cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2008;134:8.e1-8.e11.

5. Thilander B, Nyman S, Karring T, Magnusson I. Bone regeneration in alveolar bone dehiscences related to orthodontic tooth movements. Eur J Orthod 1983;5:105-14.

6. Melsen B. Palatal growth studied on human autopsy material. Am J Orthod 1975;68:42-45.

7. Harvold EP, Chierici G, Vargervik K. Experiments on the development of dental malocclusions. Am J Orthod 1972;61:38-44.

8. Proffit WR. Contemporary Orthodontics, Third Edition. Saint Louis: Mosby, Inc.;2000.

9. Bishara SE, Staley RN. Maxillary expansion: Clinical implications. Am J Orthod Dentofacial Orthop 1987;91:3-14.

10. Haas AJ. Rapid expansion of the maxillary dental arch and nasal cavity by opening the midpalatal suture. Angle Orthod 1961;31:73-90.

11. Haas AJ. Gross reactions to the widening of the maxillary dental arch of the pig by splitting the hard palate. Am J Orthod 1959;45:868.

12. Biederman W. A hygienic appliance for rapid expansion. J Clinical Orthod 1968;2:67-70

13. Isaacson RJ, Wood JL, Ingram AH. Forces produced by rapid maxillary expansion. Angle Orthod 1964;34:256-260.

14. Starnbach HK, Cleall JF. The effects of splitting the midpalatal suture on the surrounding structures. Am J Orthod 1964;50:923-924.

15. Wertz RA. Skeletal and dental changes accompanying rapid midpalatal suture opening. Am J Orthod 1970;58:41-66.

16. Ghoneima A, Abdel-Fattah E, Hartsfield, El-Bedwehi A, Kamel A, Kula K. Effects of rapid maxillary expansion on the cranial and circummaxillary sutures. Am J Orthod 2011;140:510-519.

17. Podesser B, Williams S, Crismani AG, Bantleon HP. Evaluation of the effects of rapid maxillary expansion in growing children using computer tomography scanning: a pilot study. Eur J Orthod 2007;29:37-44.

18. Garib DG, Henriques JF, Janson G, Freitas MR, Coelho RA. Rapid maxillary expansion--tooth tissue-borne versus tooth-borne expanders: a computed tomography evaluation of dentoskeletal effects. Angle Orthod 2005;75:548-557.

19. Wertz RA, Dreskin M. Midpalatal suture opening: a normative study. Am J Orthod 1977;71:367-381.

20. Velazquez P, Benito E, Bravo LA. Rapid maxillary expansion. a study of the long-term effects. Am J Orthod Dentofacial Orthop 1996;109:361-367.

21. Baccetti T. Treatment timing for rapid maxillary expansion. Angle Orthod 2001;71:343-350.

22. Chung C-H, Font B. Skeletal and dental changes in the sagittal, vertical, and transverse dimensions after rapid palatal expansion. Am J Orthod Dentofacial Orthop 2004;126:569-575.

23. Davidovitch M, Efstathiou S, Sarne O, Vardimon A. Skeletal and dental response to rapid maxillary expansion with 2-versus 4-band appliances. Am J Orthod Dentofacial Orthop 2005;12:483-492.

24. Zimring JF, Isaacson RJ. Forces produced by rapid maxillary expansion. Angle Orthod 1965;35:178-186.

25. Huynh T, Kennedy D, Joondeph DR, Bollen AM. Treatment response and stability of slow maxillary expansion using haas, hyrax, and quad-helix appliances: a retrospective study. Am J Orthod Dentofacial Orthop 2009;136:331-339.

26. Moussa R, O'Reilly MT, Close JM. Long-term stability of rapid palatal expander treatment and edgewise mechanotherapy. Am J Orthod Dentofacial Orthop 1995;108:478-488.

27. Lagravere MO, Major PW, Flores-Mir C. Long-term dental arch changes after rapid maxillary expansion treatment: a systematic review. Angle Orthod 2005;75:155-161.

28. Chamberland S, Proffit WR. A closer look at stability of surgically-assisted rapid palatal expansion. J Oral Maxillofac Surg 2008;66(9):1895-1900.

29. Geran R, McNamara J. A prospective long-term study on the effects of rapid maxillary expansion in the early mixed dentition. Am J Orthod Dentofacial Orthop 2006;129:631-640.

30. Habersack K, Karoglan A, Sommer B, Benner KU. High-resolution multislice computerized tomography with multiplanar and 3-dimensional reformation imaging in rapid palatal expansion. Am J Orthod Dentofacial Orthop 2007;131:776-781.

31. Mah JK, Danforth RA, Bumann A, Hatcher D. Radiation absorbed in maxillofacial imaging with a new dental computed tomography device. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;96:508-513.

32. Mah JK, Huang JC, Choo H. Practical applications of cone-beam computed tomography in orthodontics. JADA 2010;141(10suppl):7S-13S.

33. Periago DR, Scarfe WC, Moshiri M, Scheetz JP, Silveria AM, Farman AG. Linear accuracy and reliability of cone beam CT derived 3-dimensional images constructed using an orthodontic volumetric rendering program. Angle Orthod 2008;78:387-395.

34. Stratemann SA, Huang JC, Maki K, Miller AJ, Hatcher DC. Comparison of cone beam computed tomography imaging with physical measures. Dentomaxillofac Raiol 2008;37:80-93.

35. Lagravere MO, Carey J, Toogood RW, Major PW. Three-dimensional accuracy of measurements made with software on cone-beam computed tomography images. Am J Orthod Dentofacial Orthop 2008;13:112-116.

36. Timock AM, Cook V, McDonald T, Leo MC, Crowe J, Benninger BL, Covell DA. Accuracy and reliability of buccal bone height and thickness measurements from cone-beam computed tomography imaging. Am J Orthod Dentofacial Orthop 2011;140:734-44.

37. Garib DG, Castanha Henriques JF, Janson G, de Freitas MR, Fernandes AY. Periodontal effects of rapid maxillary expansion with tooth-tissue borne and tooth-

borne expanders: A computed tomography evaluation. Am J Orthod Dentofac Orthop 2006;129:749-758.

38. Fabiana Ballanti; Roberta Lione; Ezio Fanucci; Lorenzo Franchi; Tiziano Baccetti; Paola Cozza. Immediate and Post-Retention Effects of Rapid MaxillaryExpansion Investigated by Computed Tomography in Growing Patients. Angle Orthod 2009;79:24-29.

39. Bishara SE, Staley RN. Maxillary expansion: Clinical implications. Am J Orthod Dentofac Orthop 1987;91:3-14.

40. Ballrick JW, Palomo JM, Ruch E, Amberman BD, Hans MG. Image distortion and spatial resolution of a commercially available cone-beam computed tomography machine. Am J Orthod Dentofac Orthop 2008;134:573-82.

41. Kwong JC, Palomo JM, Landers MA, Figueroa A, Hans MG. Image quality produced by different cone-beam computed tomography settings. Am J Orthod Dentofac Orthop 2008;133:317-27.

42. Endo M, Tsunoo T, Nakamori N, Yoshida K. Effect of scattered radiation on image noise In cone beam CT. Med Phys 2001;28:469-74.

43. Ahang Y, Zhang L, Zhu XR, Lee AK, Chambers M, Dong L. Reducing metal artifacts in cone-beam CT images by preprocessing projection data. Int J Radiat Oncol Biol Phys 2007;67:924-32.

44. Katsumata A, Hirukawa A, Okumura S, Naitoh M, Fugishita M, Ariji E, et al. Effects of image artifacts on gray-value density in limited-volume cone-beam computerized tomography. Oral Surf Oral Med Oral Pathol Oral Radiol Endod 2007;104:829-36.

45. Deguchi T, Takano-Yamamoto T, Yabuuchi T, Ando R, Roberts WE, Garetto LP. Histomorphometric evaluation of alveolar bone turnover between maxilla and the mandible during experimental tooth movement in dogs. Am J Orthod Dentofac Orthop 2008;133:889-97.

46. Molen AD. Considerations in the use of cone-beam computed tomography for buccal bone measurements. Am J Orthod Dentofac Orthop 2010;137:S130-5.