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The comparison of different rapid maxillary expansion devices from periodontal tissue health and root resorption perspectives

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BOSTON UNIVERSITY

HENRY M. GOLDMAN SCHOOL OF DENTAL MEDICINE

THESIS

THE COMPARISON OF DIFFERENT RAPID MAXILLARY EXPANSION DEVICES FROM
PERIODONTAL TISSUE HEALTH AND ROOT RESORPTION PERSPECTIVES

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ABSTRACT

Background:

In contemporary Orthodontic practice, utilizing Rapid Maxillary Expansion (RME) is commonly used method to correct common sagittal discrepancies of the maxillofacial complex. Its use has a long history and has become a viable treatment option despite periods of popularity and decline. It is generally accepted that indications for RME include a wide range of skeletal discrepancies of the maxilla. The treatment for the causes of these skeletal deficiencies in the transverse dimension will need correction through the use of a variety of expansion appliances.

Various RME appliances exist currently, but each are meant to produce a desired orthopedic effect on the underlying skeletal structures in selected patients. Typically, these appliances will transmit an intermittent mechanical force via an expansion screw embedded in the device to expand the upper jaw to correct for deficiencies in the transverse dimensions of patients. The mechanical force that is developed is transferred to the dental

supports of the appliance and into the alveolar bone to create separation of various sutural segments to increase arch width of the maxilla. As a patient uses this appliance and the force is transmitted, there are unwanted effects that can occur to the surrounding hard and soft tissues. The desired orthopedic expansion is obtained during RME from direct separation of the mid-palatal suture of the maxilla; however, research has shown there are global effects on the facial complex on various sutures present in the skeleton. There are also local effects that occur at the level of the dentition, including tipping of the supporting teeth of the appliance. As a patient grows older into adolescence, the amount of skeletal and dental changes is disproportionate. As a patient matures and skeletal maturity begins to take place, dental tipping becomes a factor that can put teeth at a higher risk for being moved in the dental apparatus or outside the alveolar processes. This dramatic result can produce a reduction in bone height or possible dehiscence and recession.

The aim of this retrospective study is to analyze and interpret Tomographic images for possible correlation between, rapid maxillary expansion (RME), and resulting periodontal effects, including root resorption. Appliances we are interested in this study are two types, one, a Banded expander (Hyrax type) consisting of direct dental attachment to first premolar and first molar, and another bonded expander (Acrylic coverage type), which has a similar design as the banded, but covers the chewing

surfaces of the teeth with an acrylic type material.

Material and Methods:

The samples for this retrospective study were screened from two separate repositories containing radiographic scans pre-treatment and post expansion / post treatment. Cone-Beam Computed Tomography (CBCT) scans of 21 subjects and medical-grade spiral CTs of 20 subjects were chosen, who have been previously treated for transverse deficiencies during orthodontic therapy were selected for both types of interested orthodontic appliances. The two sample groups in the study: 1. Banded expansion device group (BaEx). 2. Bonded expansion device group (BoEx). The BaEx group had initial CBCT scans taken pre-treatment and then post-treatment. The BoEx group has pre-treatment and post-expansion imaging with spiral CT imaging. The CBCT images were oriented in all three planes of space for uniformity using a prototype software Mimics v18.0 (Materialise, Belgium) and 62 anatomic landmarks were identified on each scan. A mid-sagittal reference plane was created using the anatomical point Basion on the occipital bone, Sella in the sphenoid bone and Nasion at the suture of nasal and frontal bones. Each landmark was given an x-, y- and z- coordinate representing its three

dimensional position, along with linear and angular measurements to the reference plane were recorded using the software system.

Statistical Analysis:

Mimics v18.0 (Materialise, Belgium) software was used to calculate linear distances between corresponding landmarks and also angular measurements to the reference plane. This data was exported into Microsoft excel for analysis. Descriptive statistics of our sample and paired t-tests with a 5% significance level, or p value of 0.05, were performed.

Results:

Statistically significant changes were observed between both expanders with respect to inter-arch widths (BoEx+7.6mm, BaEx+6.5mm $p<0.01$) and increase in angulation of teeth (BoEx +10.3°, BaEx +9.4° $p<.01-.03$). Lingual cortex width increases were significant in both appliances (BoEx +.72mm, BaEx +.31mm; preRME mean 1.42mm±.3mm $p<.004$), with the molars showing the greatest increase (BoEx +.74mm, BaEx +.34mm; preRME mean 1.49mm±.4mm $p<.03$).

RME reduced the buccal bone thickness of support teeth (BoEx -.30mm, BaEx -.33mm; preRME mean 1.84mm±.35mm $p<.001$), with the molars showing the

greatest loss (BoEx $-.32\text{mm}$, BaEx $-.37\text{mm}$; preRME mean $2.10\text{mm} \pm .6\text{mm}$ $p < .01-.04$).

Although no statistically significant differences were observed in changes of lingual and buccal alveolar heights, there was a decreasing trend for both measurements in both devices. Lingual alveolar height ranged from $2.31-2.59\text{mm}$ (BoEx -0.27mm , BaEx -0.45mm $p < .1-.07$). Buccal alveolar height ranged from $2.24-2.71\text{mm}$ (BoEx -0.54mm , BaEx -0.61mm $p < .3-.4$). Root length in both appliances showed decreases post-expansion, with the bonded expanders showing greater loss (BoEx -0.68mm , BaEx -0.44mm , $p < .001$).

Conclusions:

- 1) Overall, banded and bonded expanders have similar effects from periodontal and root resorption perspectives.
- 2) These changes include increasing thickness of the lingual alveolar bone, decreasing thickness of the buccal alveolar bone, and decreases in alveolar heights and root length of the support teeth.
- 3) Although localized changes were observed in the dental alveolar supporting structures of each appliance, RME with banded and bonded expanders exhibited similar changes post-expansion.
- 4) These variables should not play a role in selection of the type of device used for rapid maxillary expansion.

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Review of Literature:

The principle objective in orthodontic treatment is to achieve a stable occlusion that allows the teeth to be placed in a specific relationship to one another to function physiologically in harmony. Positioning teeth in the correct angulation and location centered over alveolar bone will promote stability and allow teeth to function properly by distributing mechanical loading along its long axis¹. The renowned dental classification set forth by Edward H. Angle, uses differences in molar relationships to classify patients based on varying degrees of antero-posterior discrepancy, and served as a foundation for common language among the dental community². To aid understanding in the spatial placement of all the dental units, Andrews developed the Six Keys or Normal Occlusion, which serves as the basis that nature's non-orthodontic models should provide a consistent guideline we should strive for as responsible specialists³.

Locally, arch width and shape are unique characteristics of the dental arch that dictate position of teeth within the dental housing. With respect to individual patients, we understand each patient has a specific arch form that is dictated by the underlying basal bones initially and maintained by oral musculature and functional pressure⁴. Maintaining this arch form during the duration of treatment further affirms the necessity to properly position teeth in the alveolar apparatus to prevent unintended consequences. Ronay et al.

explained there is a limit between eruption of teeth into the arch and expansion beyond the alveolar envelope⁵. If teeth are moved orthodontically beyond this limit, like thru the use of an intermittent mechanical force, unstable treatment results and possible periodontal concerns can arise⁶.

Sometimes, arch forms are deficient in various dimensions that would require early treatment to ensure the sustainability of the entire dental occlusion. These deficiencies that results in a sagittal discrepancy will require a unique treatment modality to ensure adequate transverse dimension in the maxillary arch.

In contemporary orthodontic practice, the utilization of rapid maxillary expansion (RME) is commonly used method to correct an array of sagittal discrepancies of the maxillofacial complex. The use of RME procedure has a long history since Angell first reported on it in 1860⁸. Later in the dental literature, Black in 1893 to Hawley in 1912, reported on maxillary arch expansion to reaffirm the abilities of skeletal manipulation during adolescence⁷. Timms reported that McQuiellen largely discredited Angell's original theory on correction by expansion due to a lack of evidence of space opening in the anterior maxilla. These criticisms would lead to more publications from Angell on expansion mechanics and will ultimately uphold his original thesis⁸. Since this initial dramatic introduction as a viable treatment option, RME has gone through periods of increased popularity and decline. Up until around the 1940s when Graber et al. starting supporting

RME for patients undergoing orthodontic treatment for cleft lip and palate, this treatment started gaining favor among practitioners^{9,10}.

It is generally accepted that the indications for RME include a wide range of skeletal discrepancies. Posterior deficiencies leading to a constriction in the maxillary arch is one of the most prevalent malocclusions of the primary and early mixed dentitions, occurring between 8-22% of patients^{11,12}. Inconsistencies in the primary occlusion will affect the development of the permanent occlusion with respect to arch width. Consequently, a posterior cross-bite that has been inherited from the primary to the permanent dentition, has the potential for long-term effects on the growth and development of the arches and dentition¹. The causes of these skeletal discrepancies we see in patients could be either genetic or environmental and will need mechanical correction through the use of expansion appliances. In most cases, the developed cross-bite, which causes a deviation of the midline, is often accompanied by a shift away from the normal path of closure. Etiology of the cross-bite consists of many factors, including heredity, digit or tongue habits and impaired nasal airflow due to enlarged tonsils or adenoidal tissue¹³. Patients having unilateral or bilateral cross bites, possible anterior-posterior discrepancies in Class II Division I or mild Class III patients due to maxillary constriction and cleft lip and palate patients are candidates for RME^{7,10,14}. Early treatment is often recommended to normalize the transverse deficiencies prior to maturation of the underlying skeleton and

create appropriate conditions for a normal occlusion to develop. The postponement of treatment or lack of arch width has been claimed to result in prolonged treatment time and a greater risk of treatment complexities that can affect the dental alveolar apparatus as a patient ages¹⁵. It is critical to understand the capacity of the various appliances and their respective effects on the craniofacial complex as a patient grows and develops thru maturity.

Various RME appliances are meant to produce a desired orthopedic effect at the level of the underlying skeletal structures rather than moving teeth through the alveolar bone^{7,14}. Typically, the desired orthopedic expansion is obtained during RME from direct separation of the mid-palatal suture of the maxilla; however, research has shown there are global effects on the facial complex on the nasal, maxillary-zygomatic and zygomatico-temporal sutures present in the facial skeleton¹⁷. Literature has shown that as a patient grows older into adolescence, the amount of skeletal and dental changes is disproportionate, with roughly 35% of movement skeletal and approximately 65% occurring dentally¹⁸. Therefore, as a patient grows and develops and skeletal maturity begins to take place, dental tipping becomes a factor that can put teeth at a higher risk for being moved in the dental apparatus or outside the alveolar process. This dramatic result can produce a reduction in bone height or possible dehiscence and recession to occur^{18,19}. In order to predictably overcome the resistance of the mature suture, often surgically or mini-implant assisted rapid maxillary expansion (SARME/MARME) has been

employed²¹. Surgery, however, requires a partial period of hospitalization, a degree of morbidity, time loss from work and is costly depending on insurance coverage. Mini-implant supported expanders have been shown to achieve approximately 3mm of skeletal change in mature patients predictably^{23,24}. Sometimes the clinician and patient may feel the degree of malocclusion is not sufficiently disfiguring or the degree of compromising is justified when compared to the surgical risks or costs²⁴.

The majority of contemporary research has been focused on the skeletal effects of two main types of expanders used in transverse discrepancy cases. The main differences between the two screw type appliances are the presence of acrylic that contacts soft tissue of the palate (Haas-type), and the other this strictly tooth-borne in design without tissue contact (Hyrax)^{14,16,20}. Other designs exist, including an area of interest for the author's research, is the bonded expander that utilizes occlusal coverage along with the traditional expansion screw.

The initial hypothesis of possibly separating the two halves of the maxilla by mechanical separation appliances originally published by Angell was discounted due to limited radiographic substantiation. The first radiographic interpretation to visualize the skeletal effects of rapid expansion appliances on the maxilla was performed by Landsberger showing a fixed appliance intra-orally with mid-palatal separation²¹. Research later showed various nasal alterations that occur during and after RME is completed in patients²².

Following years of research involving panoramic radiographs and lateral cephalometric films, RPE has become an established method in orthodontic treatment^{23,24}.

Despite the panoramic radiographs ability for visualization for the alveolar structures of the upper and lower jaws as a whole, due to it's 2-dimensional image, it only allows for interpretation thru one plane. Some studies has resorted to cast analysis as a non-invasive way to measure dental changes²⁵. To fully investigate the dental structures accurately and precisely, CBCT utilization has allowed the clinician to quantify measurements in a one-to-one relationship.

With the aid of newly designed CBCT imaging techniques, the development of more accurate treatment modalities with respect to utilizing expansion appliances has arisen. Habersack et al. used CBCT imaging to determine the osseous effects RME had on the mid-palatal suture and surrounding affected structures of the skeleton. The conclusion was determined that within the expected dosage of radiation to the patient, the high-resolution multi-slice CT would open up a new dimension in diagnoses when treating the oro-facial complex²⁵.

In a similar study by Garibe et al., the study evaluated the effects RME by means of computed tomography (CT). The aim was to compare tooth-tissue expanders to tooth-borne expanders and effects on expansion. The study recognized the two types of expanders as the most widely used with the

difference between them being the presence or absence of acrylic. The sample for the study examined 87 young subjects presenting with Class I or Class II malocclusions with a unilateral and bi lateral cross-bites seeking orthodontic treatment. The results of the study included that the RME procedure produced significant palatal expansion in the subjects examined. The two appliances appeared to have the same desired orthopedic effect when examined with CT imaging. The amount and direction of bodily movement of anchoring teeth was the same in both appliances, with the second premolar showing more tipping than translating. The tooth and tissue expander produced a greater change in axial inclination of supporting teeth than the hyrax expander. The results of this study illustrated the effect expansion appliances have locally at the hard tissue level thru visualization with CBCT²⁶.

Evaluation of bone height by Sercan et al. showed changes in alveolar bone thickness following treatment with maxillary expansion. The study was the first to use CBCT imaging to allow for actual 3D representation of buccal bone. Traditional 2D radiographs are less appropriate for determining periodontal changes after RME. The study consisted of 24 individuals that underwent RME treatment. Each patient had a CBCT taken at the start of treatment, intra-operatively and 2-3 years post expansion. The patients all were treated with Hyrax appliances that were either two banded or four banded to anchor teeth in the maxilla. At the result of the study, there was a

decrease in the buccal bone height post-expansion and intra-operatively observed in the sample. The study did confirm that dental expansion of a deficient maxilla appears to be an effective method for correcting these discrepancies, however, they concluded there are no significant changes in bone height that would presume negative periodontal effects²⁷. This study was a precursor to reach further by analyzing local effects expansion has on the surrounding periodontium from a pre and post-treatment perspective.

Because force generated in any expansion appliance will deliver force in the form of compression on the periodontal ligament of supporting teeth, therefore it is understood that alveolar bone resorption will lead to tooth movement in that direction¹⁷. Most research to date has been concentrated on tooth-borne expanders, which will have a tendency to concentrate forces at the dento-alveolar junction²⁶. The tooth-tissue expanders, which will concentrate the force at the level of the dento-alveolar bone, was thought to be liable to create a more iatrogenic environment from a periodontal standpoint, which could lead to soft tissue damage including root resorption and recession^{26,28}. Comparisons have been made to discern the possibility regarding the impact tooth borne or tooth-tissue borne expanders and effects of force distribution between the anchor teeth and palatal alveolus²⁸.

There has been considerable research done in animal subjects to show a strong relationship between buccal movement of teeth and possible hard

tissue changes that can occur post expansion resulting in bone dehiscence's²⁹. More importantly, few researchers have looked at the importance of maintaining periodontal stability post expansion therapy in humans^{30,31}. To examine the effects of rapid and slow expansion therapy on the periodontal supporting structures, Greenbaum focused the area of interest on the buccal surfaces of the first molars³⁰. Twenty-eight patients underwent rapid maxillary expansion treated with a tooth and tissue borne appliance. The rest in the rest were treated with a slow palatal expansion appliance. This study combined slow and rapid expansion to study effects on the dentition. Periodontal parameters were recorded, including the level of the alveolar bone, attachment levels at the CEJ, probing depths and attached gingiva. The subjects were measured only at the retention phase 3-6 months later after expansion had occurred. The results showed no significantly different changes in any of the parameters tested with respect to the slow expansion and control groups. The rapid expansion did show a significantly lower periodontal attachment and bone level compared to slow expansion group results. The RME group showed worse results in all parameters measured but it was determined that none of the variables studied appeared to have a significant influence on periodontal tissues. This study served as a working hypothesis to further more research on periodontal status post expansion and any possible links to periodontal breakdown after treatment³⁰.

Unfortunately, previous research shows there is a lack of good quality imaging in conventional radiographs, which is mostly 2D records containing superimposed images and are unable to accurately depict buccal and palatal bone thicknesses³².

To further explain and identify adverse effects with the use palatal expanders have on the periodontium as a whole, Garibe et al. studied Haas type acrylic and tooth supported expanders. Understanding that alveolar bone resorption leads to tooth movement in the direction of the force, the expanders will concentrate force at the dento-alveolar junction and have the potential to cause unwanted adverse effects¹⁷. The study did not show any gingival recessions on anchoring teeth suggesting the soft tissue stayed at the original height despite a loss of hard supporting structures. Despite the small sample size, the study benefits from utilizing CT to measure inaccessible measurements clinically. Ultimately, there was lacking evidence that the induced RME in this study would directly produce periodontal issues in these patients later in life²⁶. The study concluded that there was no apparent resorption on teeth supporting the devices in both groups. Lingually, both groups saw an increase in lingual bone on supporting teeth. The tooth borne appliance showed an increase in the lingual bone at the second premolar area compared to the other appliance. The study concluded the changes in bone height and width in each expander along with RME induced bone dehiscence. This study served as a turning point for identifying possible problems

periodontally that should be considered when choosing appliances for maxillary expansion in older children²⁶.

To help understand the factors that affect buccal bone architecture post expansion therapy, Rungcharassaeng et al. studied 30 patients using CBCT imaging at initial and post treatment RME. Predictable measurements were taken and analyzed to show immediate changes in the dental angulations resulting in tipping and reduction in bone thickness buccally³³. The changes were maintained into post RME analysis and were apparent in the first molar and premolars, which further emphasized Garibe's previous study.

To complete the picture, with respect to the dentoalveolar apparatus, examination of root resorption is important to formulate an accurate representation of the entire system during expansion. Baysal et al reported in 2012 on evaluation of root volume changes after RME. In the CBCT study (n=25) of patients who had undergone RME treatment with a tooth-borne expansion appliance, scans were completed immediately before initial expansion and post-expansion. Using the 3D models, the first molars were isolated and oriented to measure from the level of the furcation to the root apices. Total root volume loss and percentage root volume loss were measured in this study. The results showed that in patients that have undergone RME therapy using a tooth-borne expander, root volumes tend to decrease after expansion, primarily on the first molars³⁴.

Barber et al. in 1981 reported on orthodontically induced root resorption, other than apical root loss, after previous research suggesting little long-term detrimental effect occurred to physiological health^{35,36}.

Later on, Odenrick et al. in 1991 examined the occurrence of root resorption in premolar anchor teeth using a fixed tooth-tissue borne expansion appliance. Premolar teeth in patients were examined radiographically at the start of treatment and at the end of expansion. To precisely identify locations of resorption lacunae, the teeth were divided into equal sections prior to measuring microscopically. The results showed buccally positioned resorption lacunae on all of the test premolars³⁷. The lacunae also became larger with respect to the CEJ, with an average distance of 1.2mm away, indicating that there is a transverse movement of the anchor teeth and not totally parallel, suggesting a degree of tipping³⁷. Observing changes in the supporting structures histologically of teeth gave a closer insight on the reactive changes that take place during expansion.

The area of research for the author's topic of interest is in the area of periodontal effects that potentially occur immediately post expansion therapy after a time point of retention and comparing between two types of expansion appliances. Most research focuses on the two major expanders, the Hyrax and Hass types, but bonded occlusal expanders are limited in the research, but still utilized in correcting transverse discrepancies^{38,39}.

The purpose of our research is to determine a relationship between various periodontal effects that could present, post-treatment, from decreasing bone alveolar height to dehiscence and root resorption in patients undergoing rapid expansion therapy for correction of skeletal transverse discrepancies using both banded (Hyrax type) and bonded (acrylic coverage type) appliances.

Materials and Methods:

Sample Selection:

Approval from the Institutional Review Board (IRB) of the Boston University Medical Campus was obtained to access two repositories of cone-beam computed tomographs for this retrospective, cross-sectional study (IRB#H-33691). These were obtained from a private Orthodontic practice in Massachusetts, taken for the purpose of diagnosis and treatment planning prior to comprehensive orthodontic treatment.

For adequate statistical power, initial pre-treatment CBCT images of 120 CBCTs of patients seeking comprehensive orthodontic treatment were selected and screened for this retrospective study. The goal of the author was to compile a sample of at least 40 usable images for 80% power, based on sample sizes from similar published studies in the literature^{9,26,40,20}. The random selection of 120 scans for screening was taken from a generated database of CBCTs. The patients in this database were selected based on a history of diagnosed posterior cross-bite, irrespective of gender, age, ethnicity

or dental malocclusion. Patients with craniofacial anomalies, any significant findings upon radiographic examination, obvious skeletal facial asymmetry or lack of quality diagnostic CBCT were excluded from the study. The database contained only de-identified DICOM files of the scans.

Inclusion Criteria:

The sample for this study was selected based on a history of diagnosed posterior cross-bite, irrespective of gender, age, ethnicity or dental malocclusion. The subjects must have been subjected to a pre-treatment and post-expansion CBCT to confirm expansion mechanics was performed to correct transverse deficiencies. Subjects in this study were separated into two groups, banded expanders (BaEx) and bonded expanders (BoEx) (Figure 1).



Figure 1: Model representations of each expansion appliance examined in this study Left: Banded Hyrax type, Right: Bonded acrylic occlusal coverage type.

Skeletal Maturation:

Skeletal maturation was assessed using the cervical vertebral maturation (CVM) index as per Figure 2. CBCT analysis of the cervical vertebrae allowed for inclusion of patients who were stages CV 4 and above. Selection of patients with CV 4 or higher was done to ensure that peak growth was likely

passed for use in analysis^{41,42}. Patients with CV 3 or below, or whose vertebrae could not allow proper analysis, were excluded from the study.

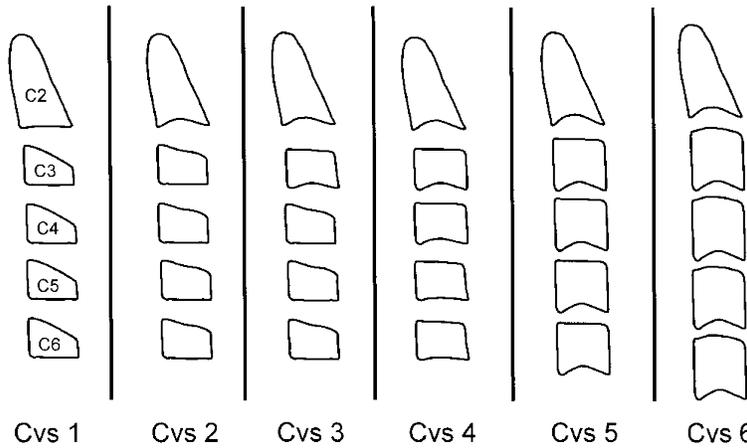


Figure 2: Developmental stages of cervical vertebrae.

Cone Beam Computed Tomography Imaging Criteria:

All CBCT scans were screened for the well-defined presence of critical anatomical structures that were necessary for landmark identification. Those scans displaying adequate extension superiorly to the cranial base and inferiorly to the cervical vertebrae were included (Figure 3). Any CBCT scan that did not meet all of these diagnostic criteria were excluded from the study.

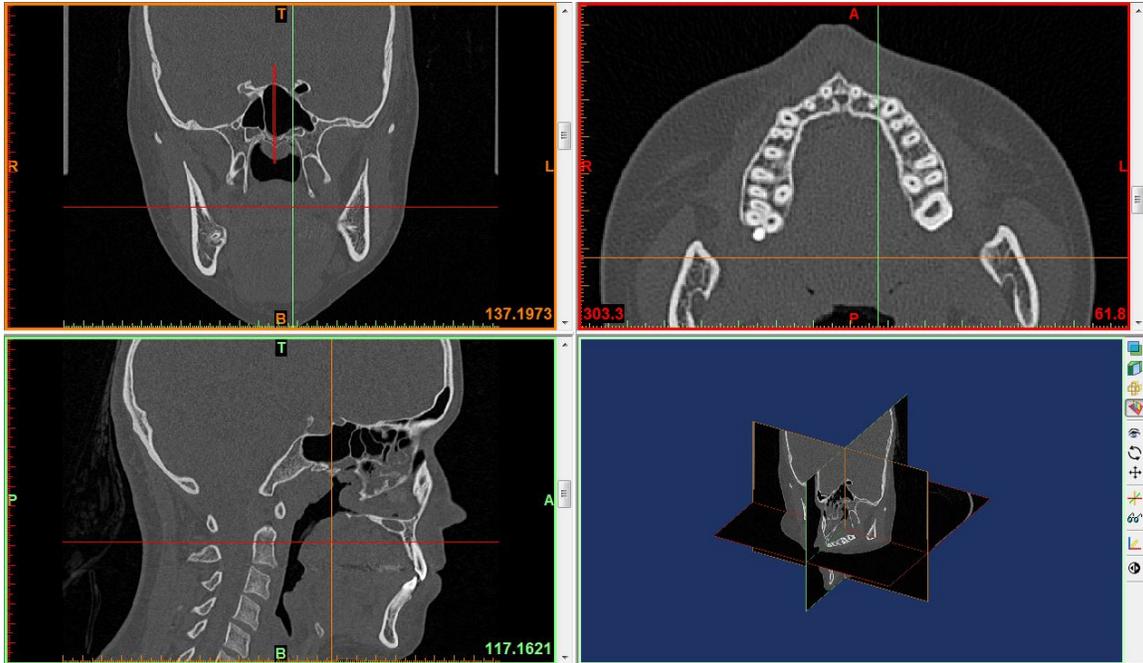


Figure 3: CBCT imaging showing complete field of view scan to allow for adequate identification of landmarks for analysis and cervical vertebrae maturation.

CBCT Image Reconstruction:

After screening for anatomy and presence of posterior cross-bite, 41 subjects met the inclusion criteria and were selected for analysis in this study. The remaining images were separated into two groups (Banded appliance or bonded appliance). All CBCT DICOM files were imported to Mimics v18.0 (Materialise, Belgium) software for image processing and analysis. To establish a standardized orientation of all images imported to Mimics, the

software used three-dimensional reference planes to orient in the coronal, axial and sagittal planes (Figure 4).

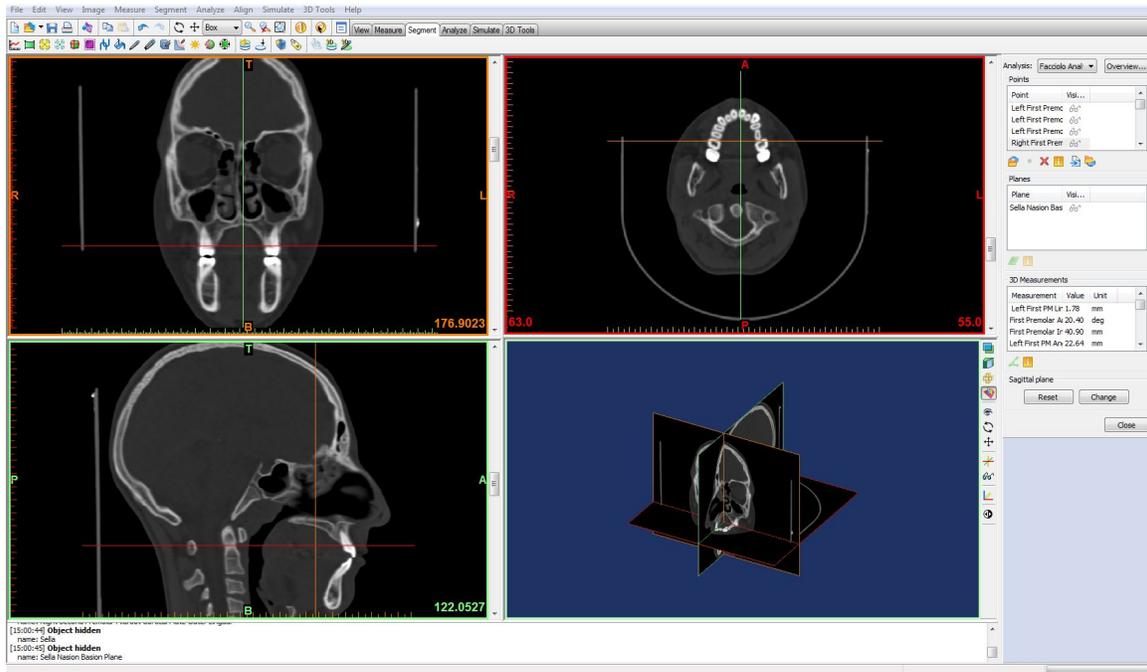


Figure 4: Depiction of imported DICOM file and proper orientation prior to digitization.

Management of Projects in Mimics:

Once the subject's DICOM file was imported into Mimics software and a new project was created for each file, the CBCT images were traced in the following manner:

First, a specific analysis was created that included all the points that wanted to be traces for each subject based on previous published literature^{26,40}. To create a new analysis, "overview" was selected inside the software display (Figure 5). Second, a new "analysis template" was created under the overview

option (Figure 6). Third, the new analysis was created under the “change analysis tab” (Figure 7). Finally, the landmarks (63 total) were then created under “new point” icon and given their specific name and color for identification (Figure 8).

After creation of the desired analysis, a new project in Mimics was initially created for each subject, then “measure and analyze” was selected under the simulate tab (Figure 9). The study that was previously created for this research was then selected under the analysis tab (Figure 10). Next, each landmark was selected individually on the upper right window and placed in its anatomic position in the axial, coronal and sagittal dimension (Figure 11).

The landmarks (Figure 12) started with identifying Nasion, basion and sella for angulation measurements. The remaining landmarks were equally distributed between the left and right dentition. Each side had identification landmarks for the following points:

First Pre-Molar, Second Pre-Molar, First Molar:

Mesiobuccal Cusp Tip

Palatal Root Apex

Buccal / Palatal CEJ

Buccal / Palatal Alveolar Bone height

Buccal alveolar thickness (Inner and Outer cortical plate)

Palatal alveolar thickness (Inner and Outer cortical plate)

Measurements were calculated from selecting the desired points and entering either linear or angulation measurements from the provided points (63 total). Linear measurements to calculate bone widths were selected from the alveolar bone height from both inner and out cortices. Alveolar bone height was measured from alveolar crest height to each corresponding CEJ. Dental angulations for each tooth were recorded from apex to cusp tip to both contralateral tooth and to the mid plane (Sella, Nasion, Basion plane). Inter-arch measurements were recorded from cusp tip to cusp tip contra-laterally, and apex to apex contra-laterally. Root length was measured cusp tip to apex for each posterior tooth (Figure 13).

After all the landmarks were accurately selected for each posterior tooth, the measurements were calculated instantaneously and then exported in TPS format from Mimics to an Excel spreadsheet document for analysis. The 3-D TPS data was then compiled for each subject, and both pre and post-expansion scans, for easy interpretation.

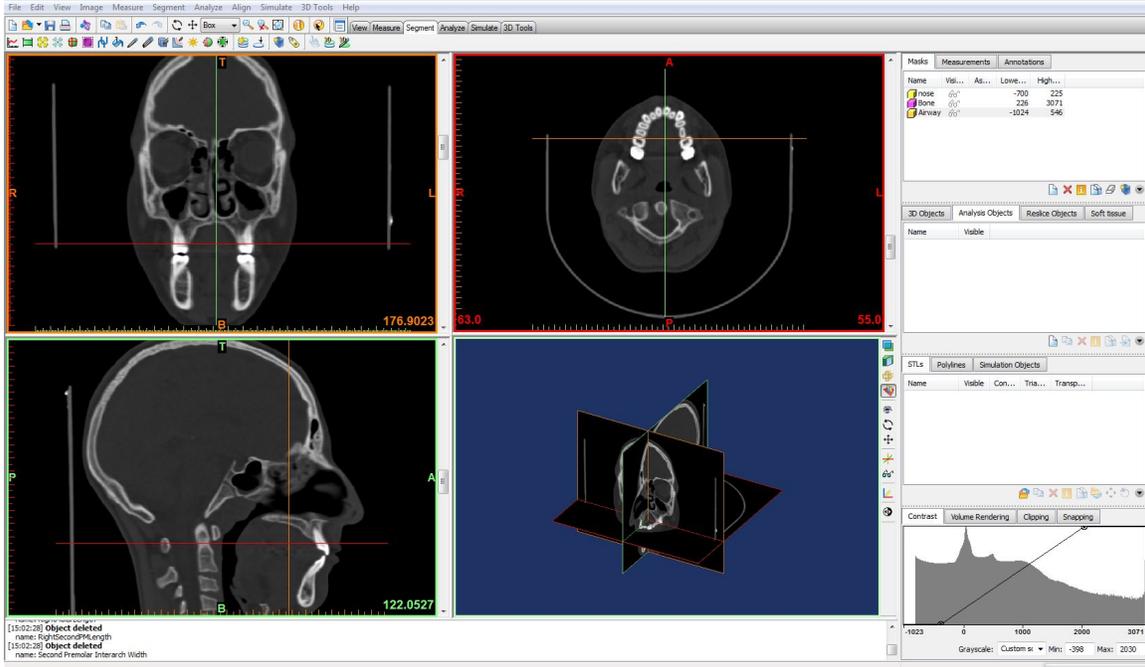


Figure 5: Select overview to create new analysis.

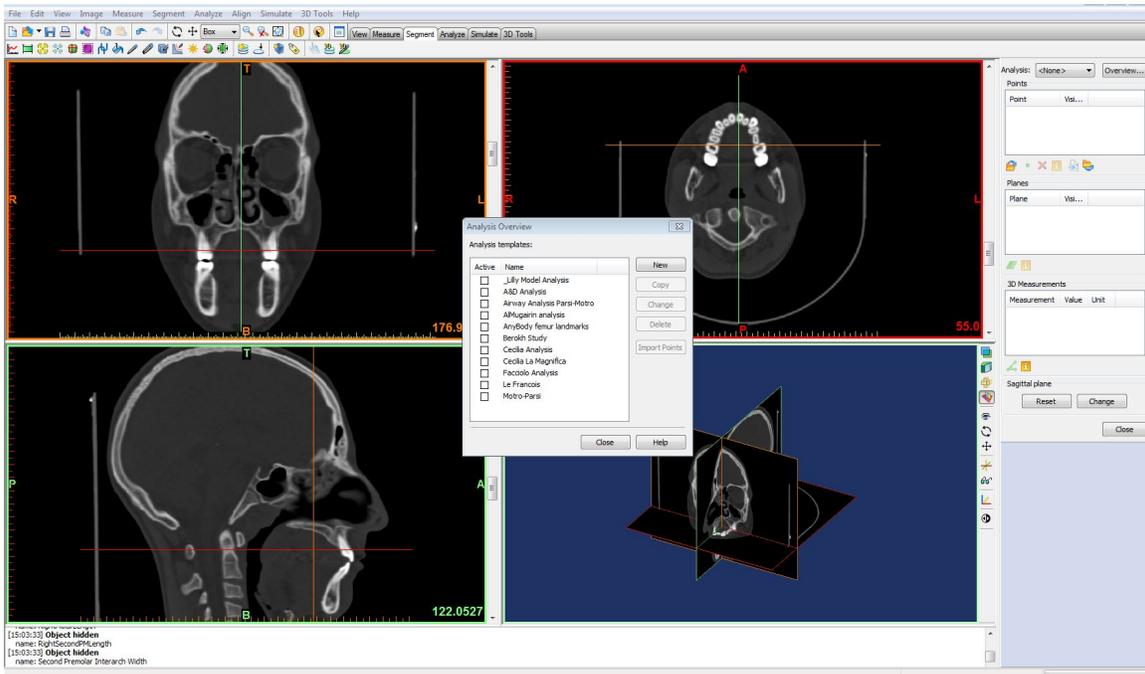


Figure 6: Select "New" under analysis template.

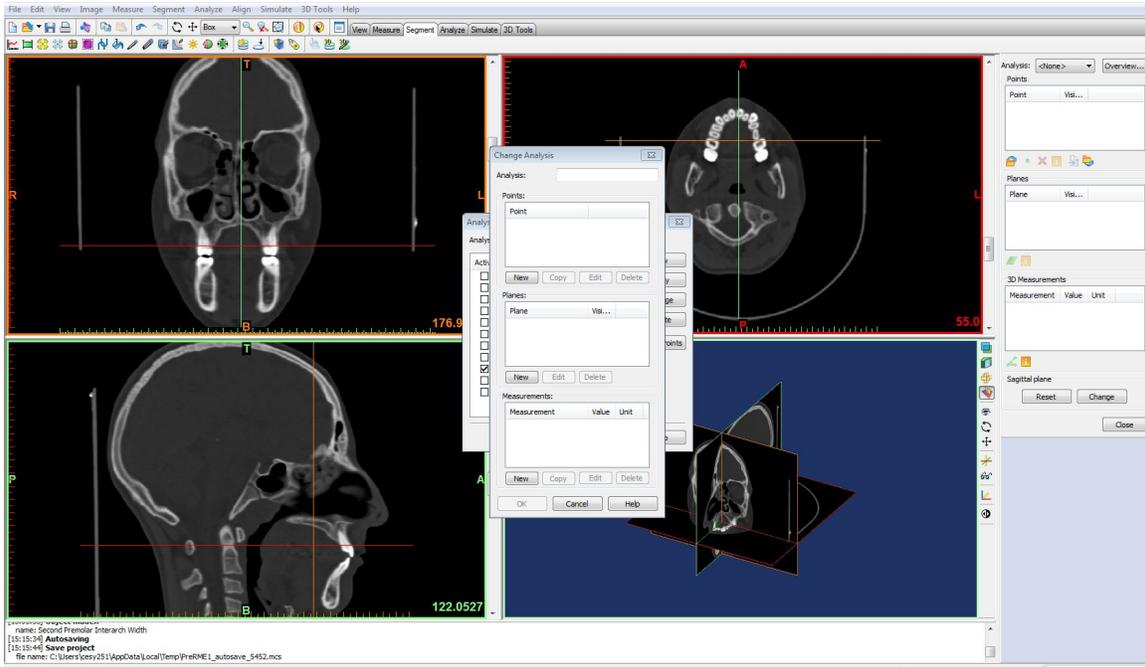


Figure 7: Create new analysis under “Change analysis”.

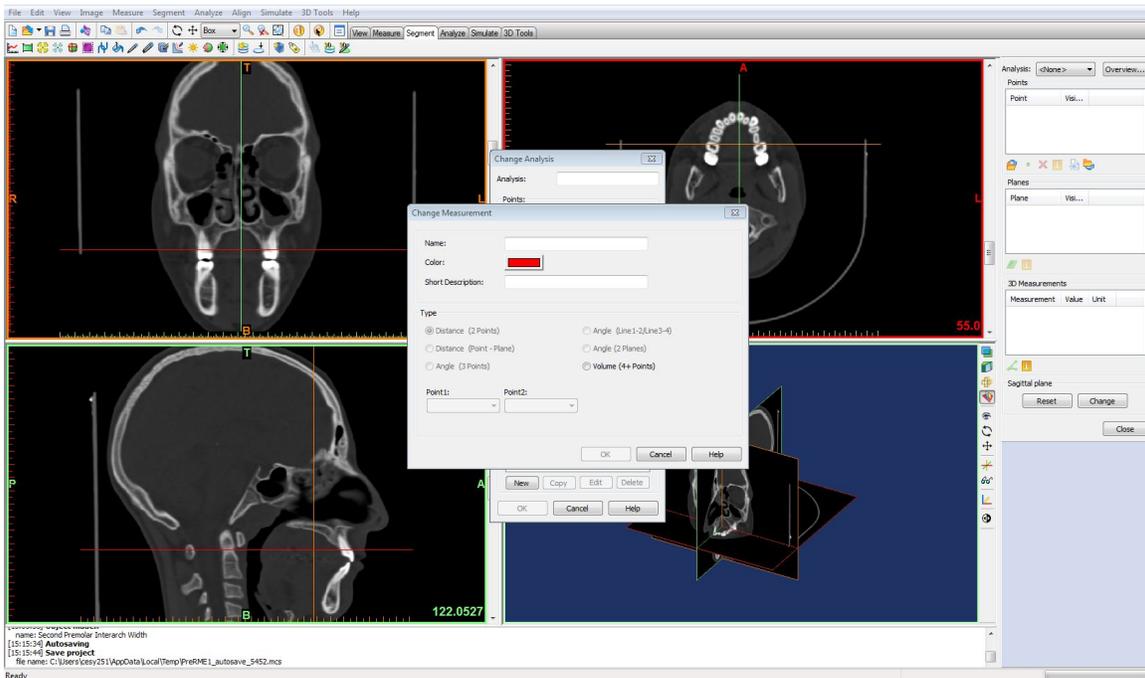


Figure 8: Create new landmarks.

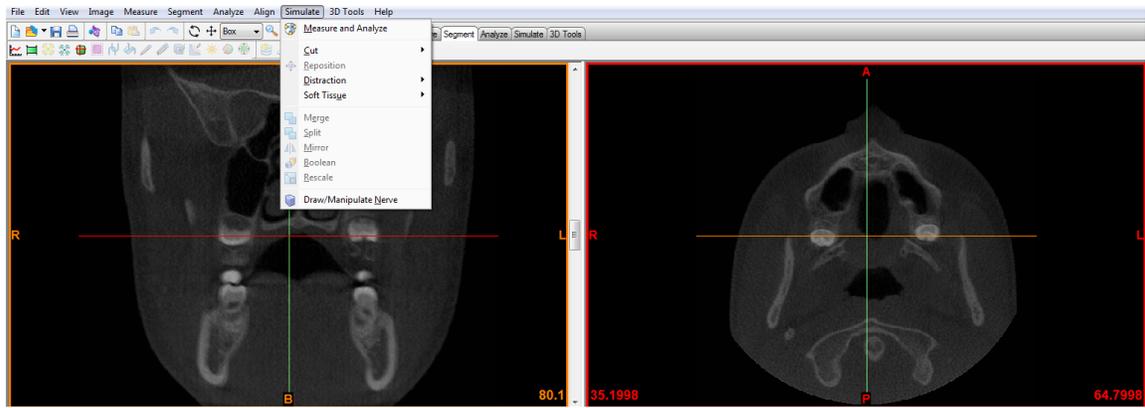


Figure 9: “Measure and analyze” was selected.

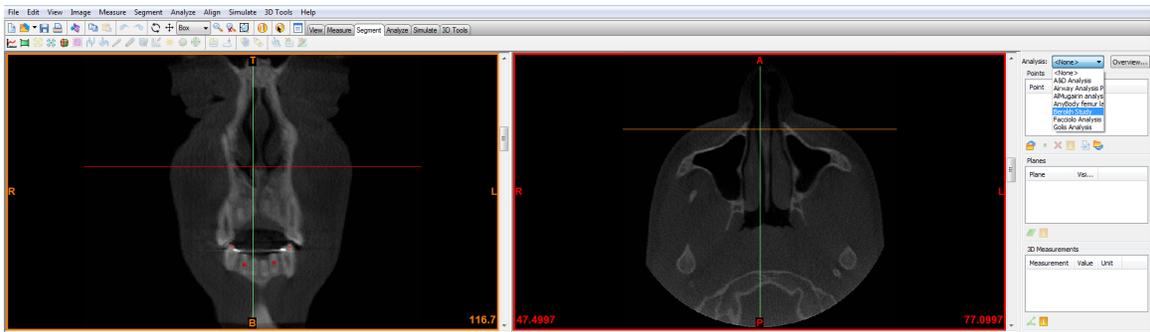


Figure 10: Select the previously made analysis.

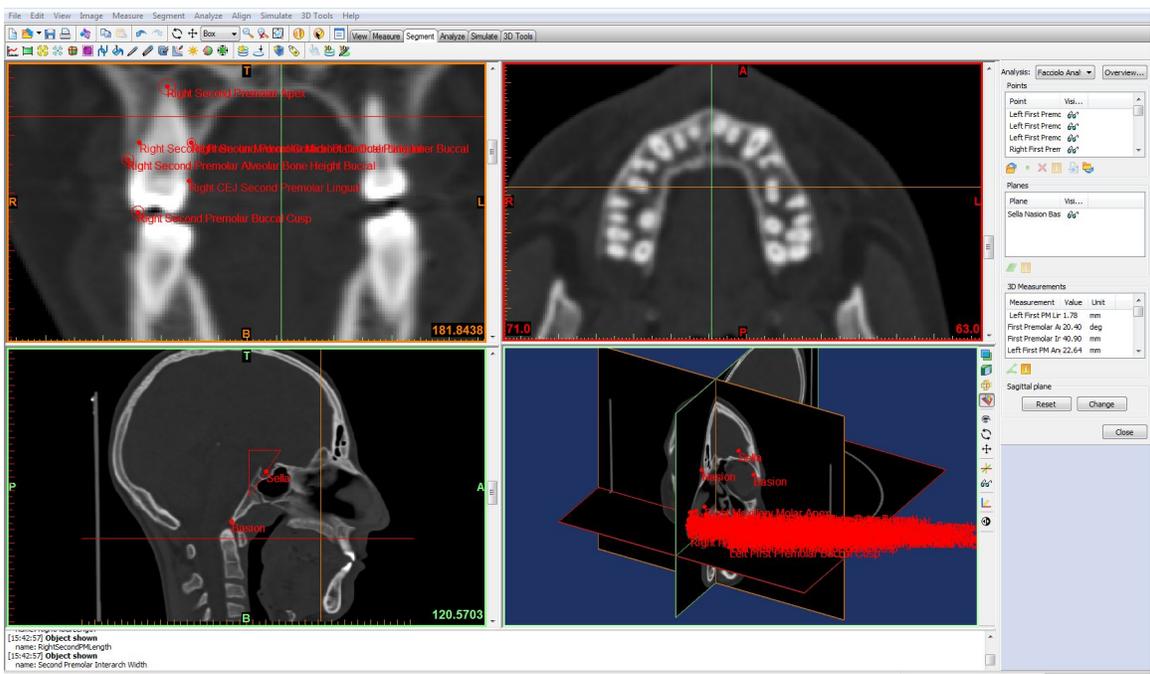


Figure 11: The landmarks selected on the Coronal, Sagittal and axial slices.

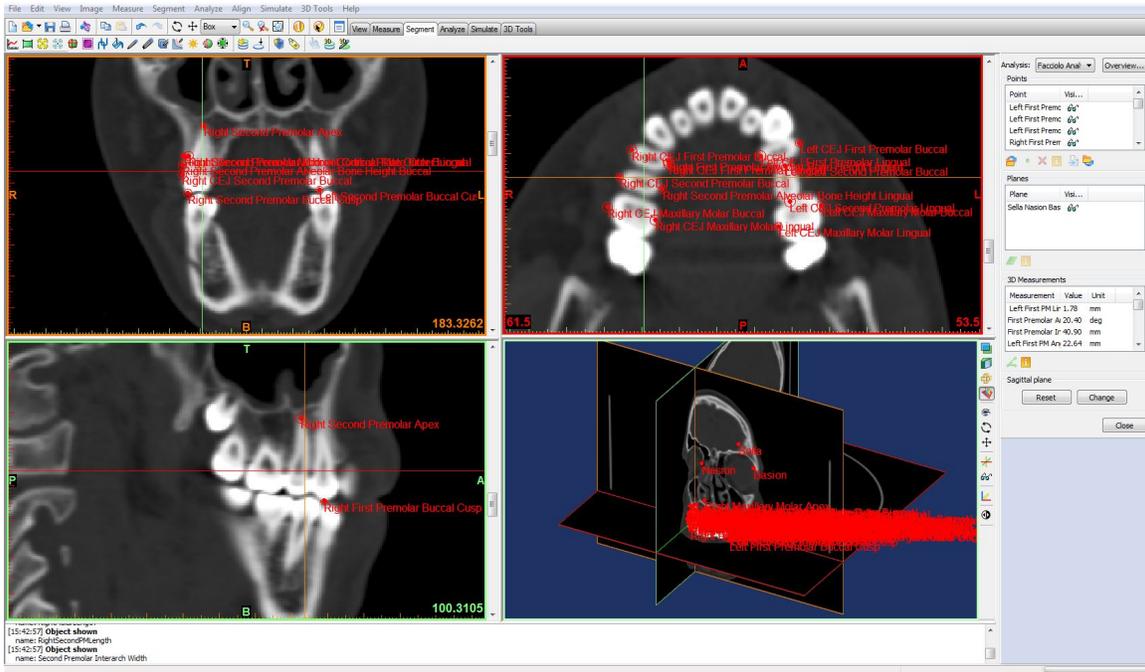


Figure 12: The 42 points of anatomic landmarks for measurement.

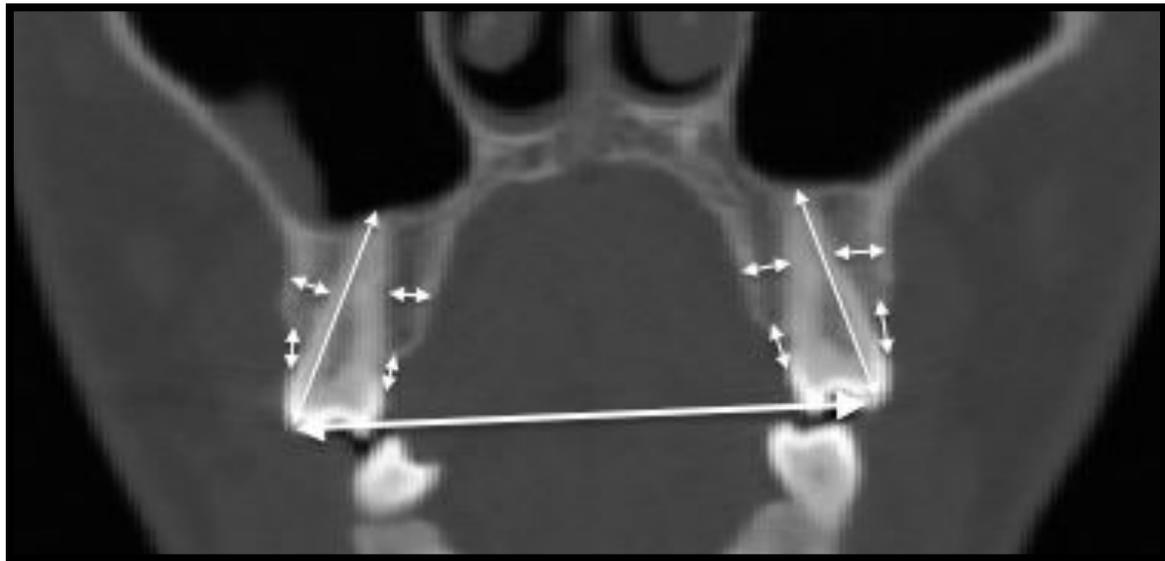


Figure 13: Coronal view to show the depiction of measurements as applied to the posterior teeth.

Statistical Analysis:

Mimics v18.0 software was used to calculate linear distances between corresponding landmarks and also angular measurements to the reference plane. This data was exported into Microsoft excel for analysis. Descriptive statistics of our sample and paired t-tests with a 5% significance level, or p value of less than 0.05, were performed.

Intra-examiner Error:

To account for landmark identification reliability, 4 randomly selected scans (2 from each appliance; 10% of the total sample) were re-analyzed in Mimics software several weeks later by the same examiner and the reliability coefficient was calculated. Each landmark demonstrated reliability of at least 89%.

Results:

Descriptive statistics:

Descriptive statistics of the sample population were performed with the results summarized below in Table 1. The total sample size was 41 patients, 20 subjects treated with bonded (BoEx) expanders and 21 with banded (BaEx) expanders, with mean age 14.4 ± 1.8 years and range from 11 to 17. (males 12.8 ± 1.8 , females 14.1 ± 1.9). In the bonded group, 9 males and 11 females with mean age of 14.7 ± 1.4 years. In the banded group, 9 males and 12 females with mean age of 14.3 ± 1.5 years.

Descriptive Statistics		
Parameter	Banded Expander (BaEx) n=21	Bonded Expander (BoEx) n=20
Gender (M/F)	(9/12)	(9/11)
Mean age (SD)	14.3 (1.5)	14.7 (1.4)
Range	12-17	12-17

Table 1: Descriptive statistics of the sample population of both banded and bonded expanders.

Paired t-tests (Comparing appliances pre and post-expansion):

Paired t-tests were performed with 5% significance level or a p value of 0.05 to compare the means of the distances and angles of both pre-treatment and post-treatment measurements from both sample groups.

Table 2 below summarizes the results of the t-test to compare pre-expansion measurements to determine statistical significance of the samples both banded and bonded. The table shows the mean for all of the measurements calculated from the designated landmarks along with standard deviations of both groups and calculated p-values. The results show the two samples are significantly significant for both appliances in pre-expansion means across several measurements.

Variable	Banded	Banded	P-Value		
First Premolar	Interarch Width	36.4±4.7	36.9±3.6	0.7	
	Angulation	16.7±6.0	20.6±7.0	0.07	
	Left	Angulation SNBa	17.6±2.9	17.1±3.3	0.7
		Lingual Cortex Width	1.3±0.3	1.4±0.4	0.5
		Buccal Cortex Width	1.7±0.4	1.3±0.4	0.009*
		Lingual Alveolar Height	3.0±1.0	3.3±0.7	0.4
		Buccal Alveolar Height	2.3±0.4	2.6±0.6	0.04(
		Root Length	14.5±1.5	13.2±1.6	0.02*
	Right	Angulation SNBa	18.0±4.3	19.8±2.0	0.1
		Lingual Cortex Width	1.4±0.3	1.3±0.2	0.3
		Buccal Cortex Width	1.7±0.3	1.3±0.4	0.001*
		Lingual Alveolar Height	2.1±0.4	2.9±0.7	<0.001*
		Buccal Alveolar Height	2.0±0.6	2.5±0.5	0.01*
		Root Length	14.7±1.4	13.3±1.1	0.002*
	Second Premolar	Interarch Width	41.3±4.9	42.1±2.6	0.5
Angulation		19.7±6.8	21.3±7.0	0.5	
Left		Angulation SNBa	20.0±2.6	19.3±2.9	0.4
		Lingual Cortex Width	1.5±0.4	1.5±0.4	0.3
		Buccal Cortex Width	1.8±0.5	1.7±0.5	0.4
		Lingual Alveolar Height	2.4±0.5	2.2±0.5	0.2
		Buccal Alveolar Height	2.0±0.5	1.9±0.4	0.5
		Root Length	14.8±1.8	13.4±1.6	0.01*
Right		Angulation SNBa	20.4±3.9	21.4±1.6	0.3
		Lingual Cortex Width	1.3±0.4	1.6±0.3	0.02*
		Buccal Cortex Width	2.1±0.2	1.8±0.5	0.08
		Lingual Alveolar Height	2.0±0.6	2.3±0.3	0.06*
		Buccal Alveolar Height	2.2±0.5	2.2±0.6	0.8
		Root Length	15.2±1.9	13.6±1.5	0.004*
First Molar		Interarch Width	45.7±4.9	45.0±3.0	0.6
	Angulation	38.4±8.2	46.7±7.5	0.002*	
	Left	Angulation SNBa	22.5±2.9	21.6±2.9	0.3
		Lingual Cortex Width	1.5±0.3	1.5±0.3	0.5
		Buccal Cortex Width	2.1±0.4	1.9±0.5	0.1
		Lingual Alveolar Height	2.4±0.6	2.5±0.5	0.6
		Buccal Alveolar Height	2.4±0.7	2.6±0.6	0.5
		Root Length	17.1±1.8	16.9±1.1	0.7
	Right	Angulation SNBa	21.8±3.4	24.9±2.3	0.002*
		Lingual Cortex Width	1.5±0.4	1.5±0.4	0.9
		Buccal Cortex Width	2.4±0.4	2.1±0.5	0.06
		Lingual Alveolar Height	2.3±0.6	2.4±0.7	0.3
		Buccal Alveolar Height	2.7±0.8	2.3±0.6	0.04*
		Root Length	17.9±1.8	16.9±1.6	0.09

Table 2. Paired t-test to compare pre-expansion measurements for both groups. Measurements denoted by the asterisks are statistically significant.

Variable		Banded	Banded	P-Value	
First Premolar	Interarch Width	44.9±3.4	41.6±3.2	0.003*	
	Angulation	29.5±5.0	29.1±7.3	0.8	
	Left	Angulation SNBa	24.8±2.9	20.4±2.8	<0.001*
		Lingual Cortex Width	1.8±0.2	1.6±0.4	0.05
		Buccal Cortex Width	1.4±0.3	1.0±0.4	0.002*
		Lingual Alveolar Height	2.2±0.6	3.3±0.6	<0.001*
		Buccal Alveolar Height	3.1±0.5	3.3±0.7	0.2
		Root Length	14.0±1.4	12.9±1.6	0.03*
	Right	Angulation SNBa	21.2±3.5	23.1±2.8	0.06
		Lingual Cortex Width	2.1±0.3	1.6±0.4	<0.001*
		Buccal Cortex Width	1.4±0.3	1.0±0.3	<0.001*
		Lingual Alveolar Height	2.7±0.4	3.6±0.8	<0.001*
		Buccal Alveolar Height	2.6±0.6	3.2±0.5	0.002*
		Root Length	14.0±1.5	12.8±1.1	0.005*
Second Premolar	Interarch Width	48.9±3.9	46.6±2.6	0.04*	
	Angulation	30.1±7.3	28.4±8.9	0.5	
	Left	Angulation SNBa	26.5±2.3	22.7±2.7	<0.001*
		Lingual Cortex Width	2.2±0.5	1.9±0.4	0.07
		Buccal Cortex Width	1.7±0.5	1.4±0.4	0.08
		Lingual Alveolar Height	2.7±0.6	2.9±0.7	0.5
		Buccal Alveolar Height	2.5±0.5	2.4±0.4	0.4
		Root Length	14.3±1.7	13.0±1.6	0.02*
	Right	Angulation SNBa	23.6±3.3	24.5±1.9	0.3
		Lingual Cortex Width	2.1±0.5	1.9±0.3	0.1
		Buccal Cortex Width	1.7±0.5	1.6±0.4	0.5
		Lingual Alveolar Height	2.3±0.6	2.8±0.4	0.006*
		Buccal Alveolar Height	2.7±0.6	2.6±0.7	0.6
		Root Length	14.4±2.1	13.2±1.6	0.05
First Molar	Interarch Width	52.7±4.1	49.9±2.8	0.02*	
	Angulation	51.1±8.8	51.2±6.9	0.9	
	Left	Angulation SNBa	28.6±3.4	24.9±2.8	<0.001*
		Lingual Cortex Width	2.3±0.4	1.8±0.6	0.01*
		Buccal Cortex Width	1.9±0.4	1.6±0.4	0.009*
		Lingual Alveolar Height	2.8±0.5	2.8±0.7	.08
		Buccal Alveolar Height	3.0±0.7	3.4±0.6	0.02*
		Root Length	16.1±1.6	16.3±1.1	0.6
	Right	Angulation SNBa	25.3±3.1	25.6±2.1	0.8
		Lingual Cortex Width	2.3±0.4	1.8±0.6	0.003*
		Buccal Cortex Width	2.1±0.5	1.8±0.5	0.05*
		Lingual Alveolar Height	2.8±0.7	2.9±0.6	0.8
		Buccal Alveolar Height	3.1±0.8	2.8±0.7	0.1
		Root Length	17.3±1.7	16.7±1.6	0.2

Table 3: Paired t-test to compare post-expansion measurements for both groups. Measurements denoted by the asterisks are statistically significant.

Table 3 above summarizes the results of the t-test to compare post-expansion measurements to determine statistical significance of the samples both banded and bonded. The table shows the mean for all of the measurements calculated from the designated landmarks along with standard deviations of both groups and calculated p-values. The results show the two samples are significantly significant for both appliances in pre-expansion means across several measurements.

Table 4 below compares the changes that occurred between means of both appliances. Overall, increases in angulation of the posterior teeth, increases of lingual alveolar bone and decreases in buccal thickness and root lengths were observed.

Variable		Bonded	Banded	P-Value	
First Premolar	Interarch Width	8.4±2.4	4.7±1.6	<0.001*	
	Angulation	12.8±3.8	8.5±3.5	0.001*	
	Left	Angulation SNBa	7.3±1.8	3.2±2.3	<0.001*
		Lingual Cortex Width	0.5±0.3	0.2±0.3	0.005*
		Buccal Cortex Width	-0.3±0.3	-0.3±0.3	0.9
		Lingual Alveolar Height	-0.8±0.5	0.02±0.4	<0.001*
		Buccal Alveolar Height	0.8±0.5	0.7±0.4	0.5
		Root Length	-0.5±0.6	-0.4±0.2	0.5
	Right	Angulation SNBa	3.2±1.7	3.3±1.3	0.7
		Lingual Cortex Width	0.7±0.4	0.3±0.2	<0.001*
		Buccal Cortex Width	-0.3±0.2	-0.4±0.4	0.7
		Lingual Alveolar Height	0.7±0.5	0.8±0.5	0.5
		Buccal Alveolar Height	0.5±0.4	0.7±0.4	0.2
		Root Length	-0.7±0.5	-0.6±0.4	0.3
Second Premolar	Interarch Width	7.5±2.6	4.6±2.0	<0.001*	
	Angulation	10.4±4.6	7.2±4.2	0.02*	
	Left	Angulation SNBa	6.5±1.9	3.5±2.0	<0.001*
		Lingual Cortex Width	0.7±0.5	0.3±0.2	0.02*
		Buccal Cortex Width	-0.1±0.5	-0.2±0.4	0.2
		Lingual Alveolar Height	0.4±0.3	0.7±0.5	0.002*
		Buccal Alveolar Height	0.5±0.5	0.4±0.4	0.3
		Root Length	-0.5±0.4	-0.4±0.3	0.3
	Right	Angulation SNBa	2.9±2.7	4.1±1.8	<0.001*
		Lingual Cortex Width	0.4±0.8	0.3±0.7	0.01*
		Buccal Cortex Width	-0.5±0.7	-0.2±0.4	0.4
		Lingual Alveolar Height	-1.0±1.1	0.1±1.5	0.01*
		Buccal Alveolar Height	-0.5±1.1	-0.08±1.1	0.9
		Root Length	-0.7±1.5	-0.01±1.8	0.4
First Molar	Interarch Width	7.0±2.1	4.9±1.9	0.002*	
	Angulation	12.7±4.9	4.5±2.6	<0.001*	
	Left	Angulation SNBa	6.2±1.8	3.3±1.3	<0.001*
		Lingual Cortex Width	0.8±0.5	0.3±0.2	0.001*
		Buccal Cortex Width	-0.3±0.3	-0.4±0.3	0.03*
		Lingual Alveolar Height	0.4±0.2	0.3±0.3	0.1
		Buccal Alveolar Height	0.5±0.4	0.9±0.6	0.05*
		Root Length	-1.0±0.7	-0.6±0.5	0.04*
	Right	Angulation SNBa	3.5±1.7	0.7±1.7	<0.001*
		Lingual Cortex Width	0.8±0.4	0.3±0.4	<0.001*
		Buccal Cortex Width	-0.4±0.2	-0.4±0.2	0.03*
		Lingual Alveolar Height	0.6±0.4	0.4±0.3	0.2
		Buccal Alveolar Height	0.4±0.3	0.5±0.4	0.4
		Root Length	-0.5±0.4	-0.3±0.3	0.02*

Table 4: Paired t-test to compare measurement changes post-expansion in both appliance groups. Measurements denoted by the asterisks are statistically significant.

Variable		Pre-expansion	Post-expansion	P-Value	
First Premolar	Interarch Width	37.7±3.2	44.8±3.5	<0.001*	
	Angulation	20.2±5.2	30.0±8.1	0.001*	
	Left	Angulation SNBa	18.7±3.6	24.4±3.5	<0.001*
		Lingual Cortex Width	1.3±0.4	1.8±0.6	0.01*
		Buccal Cortex Width	1.5±0.5	1.5±0.2	0.6
		Lingual Alveolar Height	3.6±1.2	2.5±0.8	0.04*
		Buccal Alveolar Height	3.1±1.0	2.8±0.6	0.5
		Root Length	14.3±1.3	14.3±2.4	0.9
	Right	Angulation SNBa	18.9±1.4	21.5±3.1	0.02*
		Lingual Cortex Width	1.4±0.3.4	2.1±0.3	0.01*
		Buccal Cortex Width	1.3±0.4	1.4±0.3	0.5
		Lingual Alveolar Height	2.6±0.8	2.5±0.8	0.8
		Buccal Alveolar Height	3.0±0.9	3.2±1.6	0.7
		Root Length	13.9±2.2	14.4±2.2	0.5
Second Premolar	Interarch Width	41.6±4.5	48.7±4.3	<0.001*	
	Angulation	21.4±3.8	27.7±4.6	<0.001*	
	Left	Angulation SNBa	19.5±2.1	26.0±2.2	<0.001*
		Lingual Cortex Width	1.4±0.4	1.9±0.6	0.06
		Buccal Cortex Width	1.7±0.5	1.4±0.6	0.1
		Lingual Alveolar Height	2.7±0.5	2.4±0.7	0.3
		Buccal Alveolar Height	2.3±0.7	2.7±0.7	0.09
		Root Length	14.3±2.2	14.4±2.4	0.8
	Right	Angulation SNBa	21.2±3.0	24.2±3.2	0.007*
		Lingual Cortex Width	1.4±0.5	1.8±0.7	0.1
		Buccal Cortex Width	1.8±0.4	1.3±0.4	0.04*
		Lingual Alveolar Height	3.2±1.1	2.1±0.6	0.02*
		Buccal Alveolar Height	2.9±0.6	2.4±0.9	0.2
		Root Length	15.0±2.8	14.3±2.5	0.2
First Molar	Interarch Width	47.3±4.5	52.6±5.0	0.001*	
	Angulation	43.2±8.0	49.7±7.7	<0.001*	
	Left	Angulation SNBa	23.0±3.3	28.8±3.8	<0.001*
		Lingual Cortex Width	1.4±0.3	2.0±0.6	0.05*
		Buccal Cortex Width	2.0±0.6	1.7±0.5	0.1
		Lingual Alveolar Height	2.8±0.7	2.6±0.6	0.6
		Buccal Alveolar Height	2.7±0.7	2.6±1.0	0.9
		Root Length	17.5±2.2	16.8±2.4	0.3
	Right	Angulation SNBa	22.8±2.0	26.1±3.3	0.001*
		Lingual Cortex Width	1.5±0.5	1.9±0.5	0.01*
		Buccal Cortex Width	2.0±0.5	1.7±0.8	0.4
		Lingual Alveolar Height	3.3±1.2	3.0±1.2	0.6
		Buccal Alveolar Height	3.2±0.8	2.7±0.6	0.07
		Root Length	17.9±3.1	17.1±2.1	0.2

Table 5: Paired t-test to compare measurement means for the bonded expander group before and after expansion. Measurements denoted by the asterisks are statistically significant.

Variable		Pre-expansion	Post-expansion	P-Value	
First Premolar	Interarch Width	37.2±2.9	41.0±2.5	0.001*	
	Angulation	18.8±11.3	27.8±10.5	0.007*	
	Left	Angulation SNBa	19.1±3.9	20.9±3.5	0.006*
		Lingual Cortex Width	1.7±0.7	1.6±0.6	0.6
		Buccal Cortex Width	1.2±0.3	1.0±0.4	0.1
		Lingual Alveolar Height	2.8±1.0	3.0±1.0	0.4
		Buccal Alveolar Height	3.0±1.0	2.5±0.9	0.2
		Root Length	12.8±2.0	13.4±1.9	0.2
	Right	Angulation SNBa	18.0±3.6	21.0±3.2	<0.001*
		Lingual Cortex Width	1.7±0.6	1.5±0.5	0.4
		Buccal Cortex Width	1.2±0.3	1.0±0.5	0.3
		Lingual Alveolar Height	2.5±0.8	3.4±1.1	0.04*
		Buccal Alveolar Height	2.4±0.7	3.1±0.8	0.04*
		Root Length	12.5±1.4	14.0±1.5	0.07
Second Premolar	Interarch Width	40.6±4.6	46.2±2.2	0.003*	
	Angulation	19.5±6.4	27.7±5.9	0.001*	
	Left	Angulation SNBa	19.7±2.2	22.9±3.0	<0.001*
		Lingual Cortex Width	2.4±0.8	1.9±0.5	0.2
		Buccal Cortex Width	1.4±0.5	1.4±0.5	0.9
		Lingual Alveolar Height	2.1±0.6	3.0±0.8	<0.001*
		Buccal Alveolar Height	2.2±0.7	2.2±0.7	0.9
		Root Length	12.4±1.7	13.1±1.8	0.2
	Right	Angulation SNBa	19.5±3.2	23.7±3.0	<0.001*
		Lingual Cortex Width	1.7±0.6	2.0±0.4	0.2
		Buccal Cortex Width	1.6±0.6	1.4±0.5	0.2
		Lingual Alveolar Height	2.4±1.2	1.4±0.5	0.8
		Buccal Alveolar Height	2.5±1.0	2.5±0.8	0.8
		Root Length	14.3±1.3	14.2±2.0	0.9
First Molar	Interarch Width	44.6±3.3	49.7±2.7	<0.001*	
	Angulation	47.1±10.2	50.9±9.0	0.003*	
	Left	Angulation SNBa	22.5±2.8	25.2±3.1	<0.001*
		Lingual Cortex Width	1.8±0.3	1.8±0.6	0.9
		Buccal Cortex Width	2.3±0.6	1.8±0.7	0.01*
		Lingual Alveolar Height	2.6±0.9	3.0±1.1	0.4
		Buccal Alveolar Height	2.5±0.6	3.0±1.0	0.1
		Root Length	15.3±1.7	16.1±1.4	0.3
	Right	Angulation SNBa	20.9±3.0	24.8±3.0	<0.001*
		Lingual Cortex Width	1.4±0.4	1.6±0.4	0.1
		Buccal Cortex Width	2.3±0.8	1.9±0.7	0.004*
		Lingual Alveolar Height	2.7±0.9	2.8±0.8	0.8
		Buccal Alveolar Height	2.3±0.6	2.7±0.7	0.09
		Root Length	15.8±1.3	16.7±1.1	0.02*

Table 6: Paired t-test to compare measurement means for the banded expander group before and after expansion. Measurements denoted by the asterisks are statistically significant.

Tables 5 and 6 above show the changes that occurred when comparing pre and post-expansion of the appliance to itself. Overall, when comparing the appliance from a pre and post-expansion position, the trends seen in previous studies are confirmed the aforementioned changes in increasing angulation, thicknesses of cortical bone and root lengths seen in both appliances.

Discussion:

Predictable treatment responses to transverse malocclusions, due to maxillary width deficiencies, have been well documented in children and adolescents since Haas popularized the palatal expander in the 1960s^{7,14}. When examining the opposite extreme of mature patients, the use of expansion appliances to mechanically widen the maxillary arch segments is often reported as not feasible in review of the literature^{1,9}. This negative view of rapid maxillary expansion in post-pubertal growth and mature patients, is based in part on studies of anatomical structures of the mature craniofacial skeleton, which show the mid palatal suture to be more inter-digitated resulting in rigidity by late teens⁴³.

This compromise has lead researchers to study the possibility or non-surgical RME as an alternative to a surgical/mini-implant procedure and therefore the corresponding effects to the supporting dental structures. Potential

complications of skeletally mature patients treated with RME can be summarized as stated in the literature as follows^{16,44,45,46,54}:

1: The ability of expansion is limited and is only appropriate for dental correction.

2: The results are often unstable and the chance of relapse is often common.

3: Pain is often experienced because of natural anatomical resistance to sutural separation and compression of the palatal tissue by the appliances.

4: The posterior teeth will tip leading to inappropriate angulation and poor occlusion.

5: Tipping of the teeth will lead to plunging palatal cusps of posterior teeth that leads to clockwise rotation of the mandible, opening the bite and increasing overall facial height.

6: Maxillary posterior teeth are displaced buccally through the alveolus structures leading to characterized bone loss and possible dehiscence and root resorption.

Previous reports on the efficacy of palatal expansion and its effects on the underlying bone structures are slightly limited to clinical trials and smaller samples sizes utilizing one type of palatal expander^{10,27}. This paper expands

on previous reports^{26,40} by examining radiographs of 41 patients who underwent RME with two different appliances.

Considering the results of this study, it appears that overall there are many changes that occur to the dento-alveolar structures in patients treated with RME. Both of the appliances in this study exerted a similar trend across the studied variables including increasing dental arch widths, increased angulation of posterior teeth, increasing lingual cortical thickness, decreasing buccal cortical thickness and reduction of alveolar bone height and root lengths. The trends were similar in both observed appliances; both bonded and banded expanders, with exceptions being noted in a couple of key variables measured in regards to changes and magnitude. The exceptions were seen in the level of lingual alveolar height at the first premolar in the bonded group and differences in the magnitude of the changes observed between both appliances, probable reasons for which will be discussed below.

In general for pre-treatment comparisons most measurements did not show statistical significance, as determined by a p-value of greater than 0.05, with exception in significance in lingual cortex widths, buccal cortex width, alveolar height and root length.

Comparison of the amount of expansion between each appliance:

Due to the limited nature of this retrospective study, with respect to the amount of actual expansion, we had to rely on both direct measurements taken from CBCTs and data from treatment notes described below.

The bonded RME group showed mean increases in inter-arch width from 7.2mm±2.7 in first and second premolar (7.1mm±2.1) and 5.3mm±3.3 in the molar area. In the banded RME group there was mean increases of 3.9mm±2.7 in the first premolar, 5.6mm±4.5 at the second premolar and 5.1mm±2.1 increases at the molars (Table 2,3). The expansion was similar in both BaEx and BoEx groups, showing a differential pattern of expansion between the dental supports (Figure 14). Overall there was sufficient expansion to correct all of the posterior cross-bites as noted by examination of the post-expansion CBCTs. The molars and premolars at the T2 time point show over-correction due to well-documented relapse that occurs post-expansion⁹. Studies in the mixed dentition phase of patients indicate there is a considerable loss of transverse expansion in the form of recovery of the molars, approximately 20%-30% of the original expansion width⁴⁷. This over-expansion protocol to prevent lingual cross-bites post treatment is well followed in modern RME protocols clinically.⁹

Finally, the amount of desired expansion observed in this study was directly related to the severity of the malocclusion at the start of treatment, as identified by the clinician. There was no upper limit recorded to calculate a ceiling for expansion in any patient, but ranges of 5mm to 8mm in the bonded

group and 5mm to 10mm in the banded group were recorded as changes in arch width.

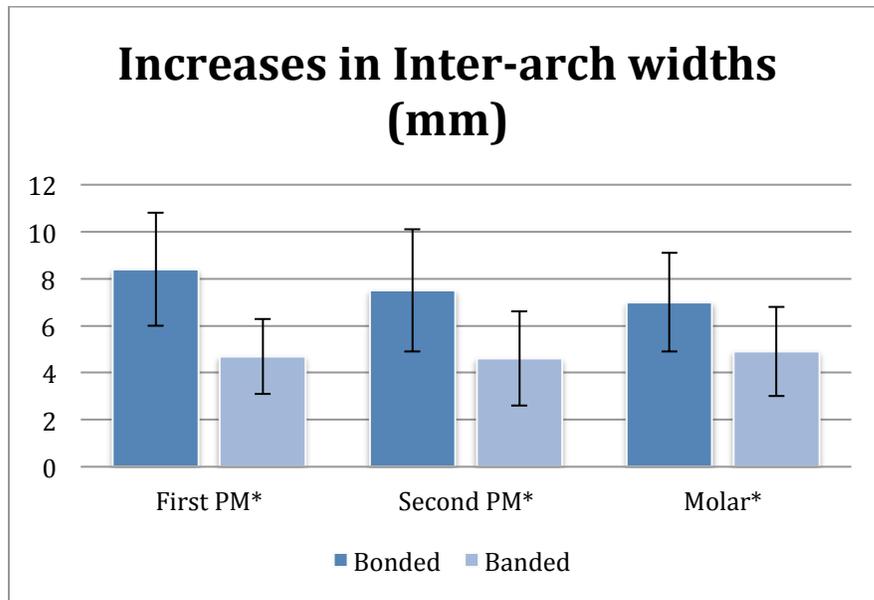


Figure 14: Shows the changes in inter-arch widths from pre-treatment to post-treatment of each appliance and each support tooth with SD.

Comparison of the amount of dental tipping of posterior teeth and effects:
 Pre-treatment analysis of changes showed there was no significant differences in angulation of any supporting teeth, premolars and molars (Table 1). When comparing the pre and post-treatment angulations, the BoEx group showed mean increases in angulation for the first pre molar of $9.8^{\circ} \pm 5.8^{\circ}$, second premolar increased $6.2^{\circ} \pm 3.6^{\circ}$ and molars increased by $7.0^{\circ} \pm 3.4^{\circ}$. The BaEx group showed mean increases in angulation for the first premolar of $8.8^{\circ} \pm 6^{\circ}$, second premolar increases of $8.2^{\circ} \pm 5.1^{\circ}$ and molars increased by $3.8^{\circ} \pm 2.1^{\circ}$. Both appliances showed the same characteristic expansion with more expansion seen in the premolar region and less in the

molar area (Figure 15). The amount of tipping of the posterior teeth was greater in the BoEx than the BaEx group. These results confirm the lack of skeletal effect from expansion in the bonded groups, which is translated from increased inter-arch width to increased tipping.

As expansion occurs in more mature patients, the amount of dental expansion observed is greater than the anticipated skeletal expansion. The results of the change in angulation of support teeth are different than a similar study by Handelman et al., which averaged approximately 3.1° change per side^{49,50}, but are in line with a previous study by Asanza in 1997, showing no differences in dental tipping when comparing bonded and banded appliances⁵⁹. The differences in mean change in angulation from the Handelman study is most likely due to the increased age of the sample studied (range 18.8-49.3 years for adult RME) and the analysis was primarily on model casts angulations of crowns, not radiographic analysis of root apices.

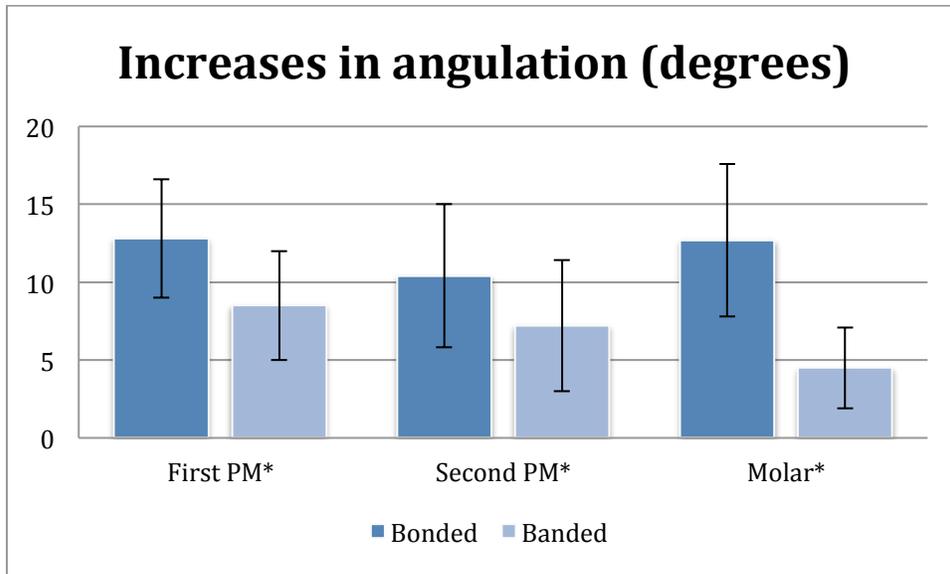


Figure 15: Shows the changes in angulation of the posterior teeth from pre-treatment to post-treatment of each appliance and support tooth with SD.

Comparison of the amount of expansion with effects on lingual and buccal alveolar bone height:

Alveolar bone height changes were measured in two locations for each dental support per appliance. Pre-treatment there was no significant differences in mean bone height of buccal or lingual alveolar height with the exceptions of lingual alveolar height at the left first premolar and the right molar buccal alveolar height (Table 1) when comparing BaEx and BoEx. When comparing the pre and post-treatment mean heights, the BoEx group showed overall mean reduction of lingual bone height of the first premolar -1.0 ± 1.2 mm left, -0.1 ± 1.3 mm right, the second premolar showed reduction of $-0.3 \text{mm} \pm 1.0$ left, -1.0 ± 1.1 mm right, and molars showed reduction of -0.1 ± 0.9 mm left and -0.3 ± 1.6 mm right. The overall mean reduction of buccal bone height of the first premolar showed reduction of -0.3 ± 1.4 mm left,

0.1±2.0mm right, the second premolar showed reduction of 0.4±0.7mm left and -0.5±1.1mm right, and the molars showed reduction -0.03±1.3mm left and -0.5±0.8mm right (Figure 16,17).

The BaEx group showed changes in lingual alveolar height of the first premolar of 0.2±0.9mm left, 0.8±1.0mm right, the second premolar showed mean changes of 0.9±0.5mm left, 0.1±1.5mm right, and the molars showed changes of 0.3±1.1mm left and -0.4±0.5mm right. The mean reduction of buccal bone height of the first pre molar showed an increase of -0.5±1.0mm left and 0.8±1.1mm right. The second premolar showed changes of -0.01±1.0mm left and -0.08±1.1mm right. The molars showed reduction of 0.5±0.9mm left and 0.3±0.6mm on the right. These changes in bone heights for both appliances are similar to results in previous research^{20,26,40}.

The results that showed statistical significance in both BaEx and BoEx were of the lingual alveolar height at the right first premolar, lingual alveolar height at the left second premolar and buccal alveolar height at the right molar (Table 7).

When analyzing the measurements that were significant, we see reduction in the bone height on the buccal and lingual alveolus in the BEx group and a gain in vertical height on the BoEx group for the same measurements. It is expected that the increase in expansion will cause increase tipping that would have a reaction on the alveolar height of each tooth. The literature suggests that frequent association of reduction of bone height with labially

positioned incisors or canines is a common occurrence and is often found in conjunction with increased proclination of teeth^{51,52,53}.

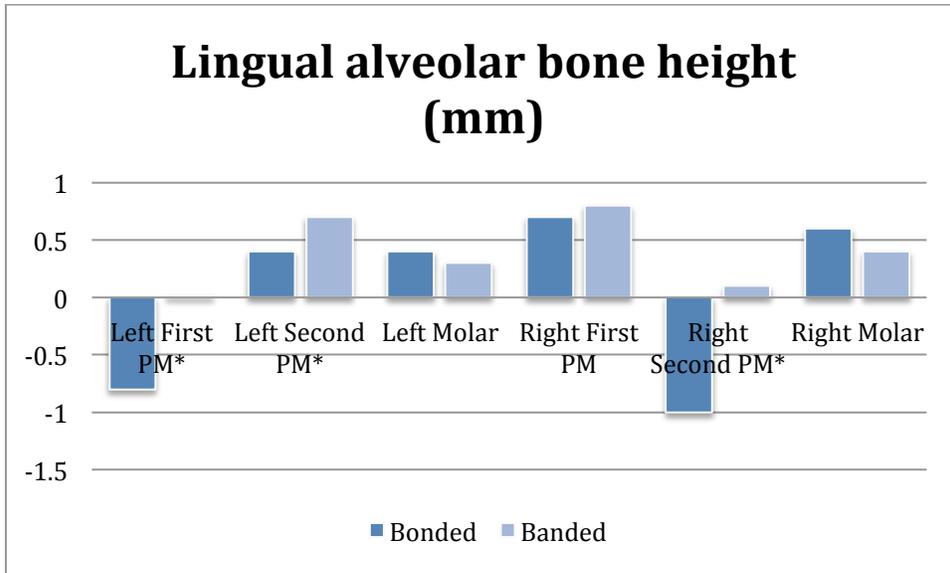


Figure 16: Shows the changes in lingual alveolar bone height of the posterior teeth from pre-treatment to post-treatment of each appliance.

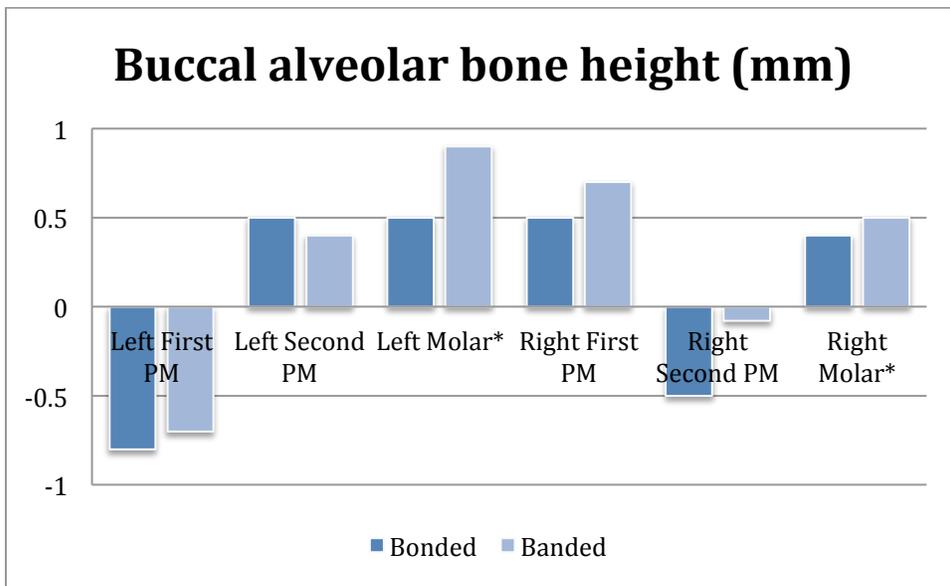


Figure 17: Shows the changes in buccal alveolar bone height of the posterior teeth from pre-treatment to post-treatment of each appliance.

Comparison of the amount of expansion with effects on buccal and lingual cortical thickness:

Cortical bone thicknesses were calculated using two measurements to assess the changes in thickness of pre and post-expansion treatment. The measurements were taken at the mid root level of each tooth from both appliances from the cortex of the inner and out alveolar plate.

Pre-treatment there was no significant differences in mean bone thicknesses of buccal or lingual cortices with the exceptions of lingual cortex at the left first premolar and lingual cortex of the right molar.

When comparing the pre and post-treatment changes in mean of cortical thickness, overall the BoEx group showed increases lingual cortical thicknesses, and reduction in buccal thicknesses (Table 7).

The mean amount of increase in lingual thickness is consistent thru all posterior teeth and the reduction seen on the buccal aspect, excluding the first premolar increases, is consistent as well.

The BaEx group showed similar results to the BoEx group, with increases in lingual cortical thicknesses and reduction of buccal thicknesses. Exceptions were noted in lingual cortex of the left second premolar and left first premolar. These results are conflicting with the rest of the trend of reduction of buccal thickness and increase in lingual thicknesses (Figure 18,19).

Overall, the trend in the BoEx and BaEx group was the reduction of buccal thicknesses and increases in lingual cortical width, which has been reported

on in a previous study¹⁵. It was expected that when increasing the transverse width of the maxilla by mechanical expansion, dental tipping is a result of a lack of skeletal alteration; the force felt on the alveolar structures will cause periodontal changes. These changes are well studied and the results show similar results in the reduction of buccal cortical thicknesses, suggesting a lack of compensation of the dental alveolar housing to accommodate the force generated from the expansion appliance^{51, 52}. The amount of change found within our results suggests similar changes with respect to both bonded and banded expansion appliances. The reduction in buccal and increase lingual thicknesses are similar to previous studies that examined changes with similar appliances^{20,26,40}.

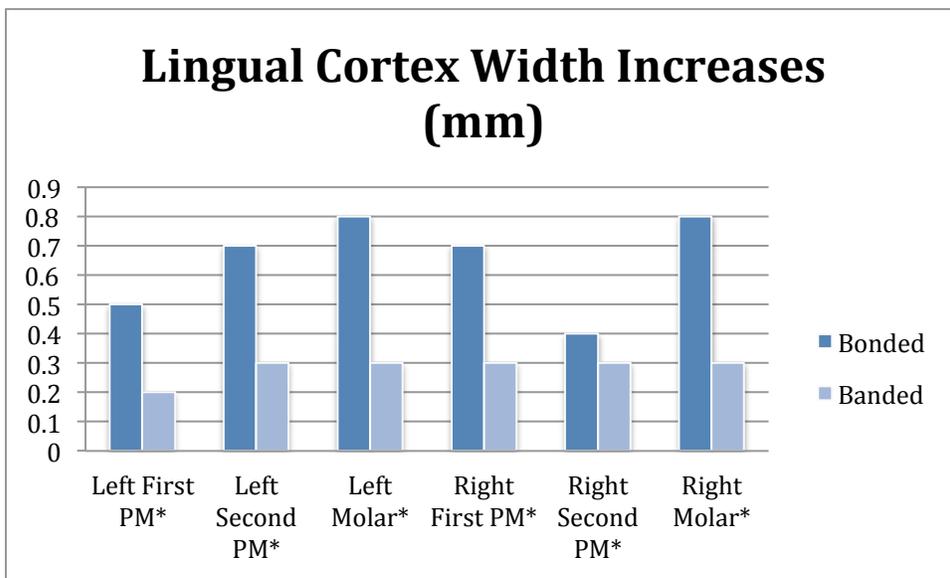


Figure 18: Shows the changes in lingual cortex width of the posterior teeth from pre-treatment to post-treatment of each appliance.

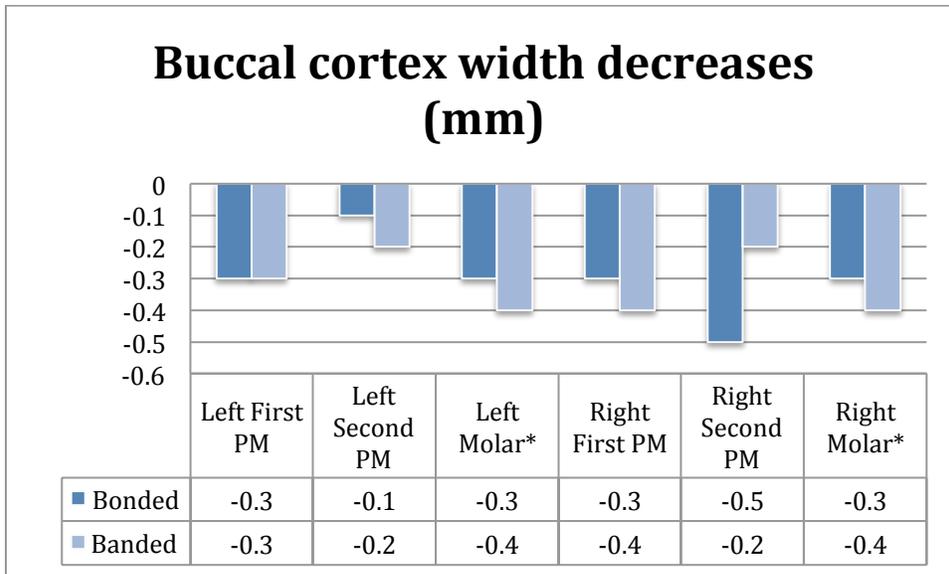


Figure 19: Shows the changes in buccal cortex width of the posterior teeth from pre-treatment to post-treatment of each appliance.

Comparison of the amount of expansion with approximate root length loss:

The potential for root length loss was measured and analyzed for all posterior teeth as explained in the material and methods.

Pre-treatment measurements of root length showed no statistical significance between both measured appliances, but analyzing comparisons of changes made after expansion, there was an exception in the root length of molars only.

Overall, the changes that occurred post-expansion showed conflicting results with respect to absolute reduction in root length (Table 7). The BoEx group showed reduction in all teeth measured with the exception of the right first premolar. The BaEx group showed similar reduction in tooth length but

showed mild root length increases in more teeth (first premolars and left second premolars).

The mean changes recorded showed a greater loss in the bonded appliances when compared to the banded appliance across all examined teeth. This trend suggests there is a relationship between the amount of expansion and the outward effect on the root apical structures, which was similar to previous studies⁴⁸ (Figure 20).

The analysis of these measurements is taken from a CBCT image of the roots supporting each appliance, it should be noted clinical examination was not readily possible and is difficult to obtain predictably. Root morphology is varying from patient to patient, and radiographic imaging is not precise enough to detect the smallest changes that could possible occur at the root apices^{55,57}. The imaging field of view was large in this sample size, approximately 13cm, but imaging slices are narrowed to .2-.3mm, thus limiting our ability to discern the changes that have occurred. Previous studies have shown root alterations that can occur after maxillary expansion to include localized surface resorption of roots on extracted teeth^{56,58} after expansion. In those studies, the extracted teeth were analyzed to detect changes in root surface at the apical level. The changes in root length studied were consistent with the results of our radiographic findings. Separate studies by Garib and Killiany both showed root-shortening changes after expansion therapy from a CBCT reconstructed image and from a histological

viewpoint. These changes support the findings in this study that changes occur radiographically and histologically post-expansion therapy^{20,60}.

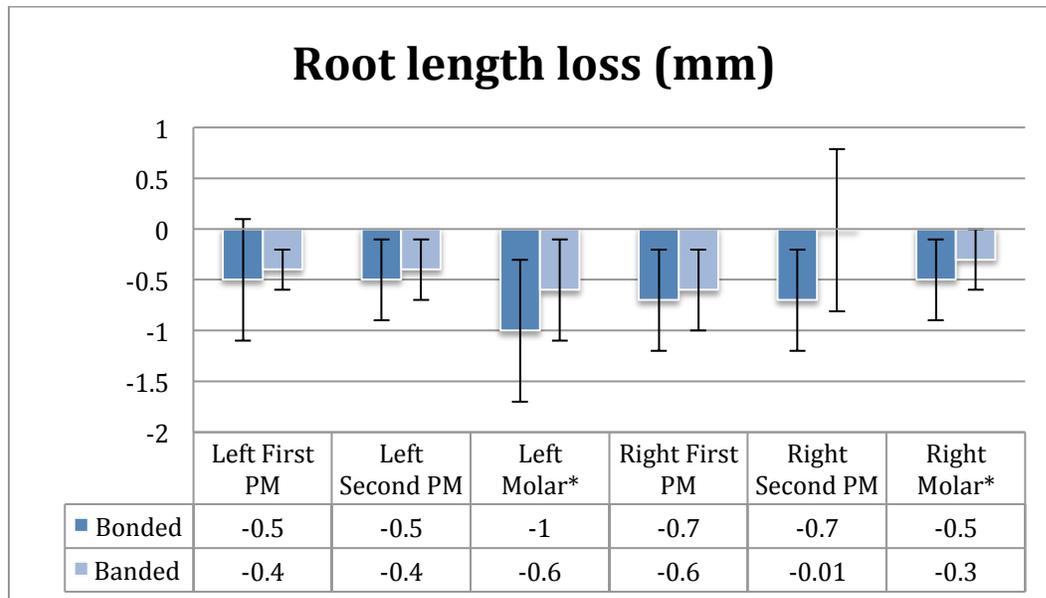


Figure 20: Shows the changes in root length bone of the posterior teeth from pre-treatment to post-treatment of each appliance with SD.

Banded	Inter-arch Width	Angulation	Cortex Width Left (L/B)	Cortex Width Right (L/B)	Alveolar Height Left (L/B)	Alveolar Height Right (L/B)	Root Length Left	Root Length Right
First PM	8.4mm±2.4 mm	12.8°±3.8°	0.5±0.3mm / -0.3±0.3mm	0.7±0.4mm / -0.3±0.2mm	-0.8±0.5mm / -0.8±0.5mm	0.7±0.5mm / 0.5±0.4mm	-	-0.7±0.5mm
Second PM	7.5mm±2.6 mm	10.4°±4.6°	0.7±0.5 / -0.1±0.5mm	0.4±0.8m / -0.5±0.7mm	0.4mm±0.3 / 0.5±0.5mm	-1.0±1.1mm / -0.5±1.1mm	-	-0.7±1.5mm
Molar	7.0mm±2.1 mm	12.7°±4.9°	0.8±0.5mm / -0.3±0.3mm	0.8±0.5mm / -0.3±0.3mm	0.4±0.2mm / 0.5±0.4mm	0.6±0.4mm / -0.4±0.3mm	-	-0.5±0.4mm
Banded								
First PM	4.7mm±1.6 mm	8.5°±3.5°	0.2±0.3mm / -0.3±0.3mm	0.3±0.2mm / -0.4±0.4mm	0.02±0.4mm / -0.7±0.4mm	0.8±0.5mm / 0.7±0.4mm	-	-0.6±0.4mm
Second PM	4.6mm±2.0 mm	7.2°±4.2°	0.3±0.2mm / -0.2±0.4mm	0.3±0.7mm / -0.2±0.4mm	0.7±0.5mm / 0.4±0.4mm	0.1±1.5mm / -0.08±1.1mm	-	-
Molar	4.9mm±1.9 mm	4.5°±2.6°	0.3±0.2mm / -0.4±0.3mm	0.3±0.2mm / -0.4±0.3mm	0.3±0.3mm / 0.9±0.6mm	0.4±0.3mm / 0.5±0.4mm	-	-0.3±0.3mm

Table 7: Comparisons of parameters showing changes in pre and post-expansion measurements.

Conclusions:

Analysis of the maxilla in three dimensions utilizing CBCT imaging shows the profound effect RME has on the dento-facial complex. In our sample it was revealed the multifactorial nature of expansion and its changes, to not only the dental angulation, but also the alveolar height, thicknesses and root lengths. Overall, these results suggest trends of increased angulation during excessive expansion in non-growing patients, decreases in alveolar bone height, thickening of the lingual cortex, reduction in width of buccal alveolar bone and decreases in tooth root length were observed. The results suggest there are limited differences between the two appliances and it is not meant to be a deciding factor for preferring one appliance to another. The plausible reasons for the basis of that decision were discussed above.

The data from this study supports the general trends that have been accepted about expansion appliances since researchers have been investigating their effect on the craniofacial complex. In terms of finite changes that are observed with respect to these two types of appliances, the changes seen at the level of the periodontium are consistent with a few studies that considered different appliances and treatment at different age ranges. Because this study was not the first of its kind, but rather a deeper investigation into expansion appliances affects on surrounding tissues, our data and results can provide a useful benchmark to further investigate these appliances or compare other types. Furthermore, our methodology can be

used to continue to explore the vast information that exists within CBCT images, and with a larger sample size it is possible to validate findings with increased landmarks for greater acuity and insight into possible changes in the dento-alveolar structures.

Strengths:

Using CBCT imaging, instead of traditional 2-dimensional imaging or plaster cast analysis, allows for direct measurements to interpret accurately both, linear and angular changes that occur pre and post-expansion. Previous studies utilized CBCTs, but with fewer landmarks, giving a limited picture of changes that occurred locally. This study narrowed the window of time down to pre-treatment and post-treatment, to limit the interaction of outside orthodontic forces that could affect the periodontium over the course of comprehensive care and changes that occur in retention.

Future Studies:

All of the subjects in this study had imaging taken pre-treatment and immediately post-expansion, which is a strength described above, but the long term effects of expansion could also be studied as a patient enters the retention phase of orthodontics.

Additional long-term studies could evaluate for possible changes to occlusal plane or mandibular plane angulations post-expansion, to analyze the dental tipping effects in the maxilla.

Furthermore, adding clinical background information derived from in-depth dental history from subjects; such as periodontal status, amounts of keratinized tissue or correlation with probing depths; could be assessed to give a more clinical representation of changes post-expansion.

Summary:

1. We traced the CBCT images of 41 subjects; landmarks were distributed across the maxilla on dental and alveolar structures to evaluate possible changes that occur to the dento-alveolar complex.
2. When comparing pre and post-expansion landmark means, variation occurred in posterior teeth angulation, cortical thicknesses, alveolar height and root length.
3. General trends seen in this study are in line with previous studies, which investigated the effects of different types of expanders.
4. More data is needed for conclusive results regarding a correlation between clinical implications of expansion appliances and their effects on the periodontium.

Conclusion:

1. Overall, banded and bonded expanders have similar effects from periodontal and root resorption perspectives.

2. These changes include increasing thickness of the lingual alveolar bone, decreasing thickness of the buccal alveolar bone, and decreases in alveolar heights and root length of the support teeth.
3. Although localized changes were observed in the dental alveolar supporting structures of each appliance, RME with banded and bonded expanders exhibited similar changes post-expansion.
4. These variables should not play a role in selection of the type of device used for rapid maxillary expansion.

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37. Surface resorption following two forms of rapid maxillary expansion

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