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Alveolar Bone Thickness after Orthodontic Treatment with and without Rapid Maxillary Expansion

by

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Submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry

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DEDICATION

This thesis is dedicated to my wife and family. I am sincerely grateful for your unconditional love and unending support. I have fulfilled my goal of becoming an orthodontist because you were all a part my life.

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Alveolar Bone Thickness after Orthodontic Treatment with and without Rapid Maxillary Expansion

Abstract

by

BRENT C. PAULUS

Objectives: To detect a difference in bone thickness supporting the maxillary first molars between patients treated with rapid maxillary expansion (RME) and patients treated without expansion following orthodontics. To relate bone thickness supporting the maxillary first molars to the amount of expansion. Methods: The RME group consisted of 17 male and 15 female patients, with a mean age of 13.67 ± 1.25 years. The non-expansion group consisted of 17 male and 15 female, with a mean age of 13.82 ± 0.67 years. CBCT images were used to measure intermolar width and bone thickness supporting the maxillary first molars. Results: Subjects with RME had a mean intermolar expansion of 3.05 mm ± 2.10 mm, ($P < 0.001$). The mean thickness of bone on the mesiobuccal significantly decreased from 1.46 mm to 1.18 mm ($P < 0.001$). There was no correlation between the change in

intermolar width and change in mesiobuccal bone thickness of the maxillary first molars. Conclusions: There was a statistically significant decrease of bone thickness on the mesiobuccal surface of the maxillary first molars after orthodontic treatment of patients treated with RME compared to patients treated without expansion. However, the difference was not considered clinically significant.

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LITERATURE REVIEW

The maxilla is formed through intramembranous ossification and is composed of trabecular bone surrounded by cortical bone (Lekhom et al, 1985). In a study completed by Bjork and Skieller et al in 1976, lateral implants were placed in the maxilla of patients and were used as reference points during maturation. Vectors of growth were determined and sutural growth was calculated. They report development of maxillary height by "growth at its processes, suturally towards the frontal and zygomatic bones and appositionally on the lower aspect of the alveolar process in association with eruption of the teeth." In addition, the midpalatal sutural growth contributes more to the width of the maxilla than appositional remodeling.

During the course of dentofacial development, dental or skeletal crossbites can develop. In 2007, an epidemiologic study done by da Silva Filho et al, 2,016 children, aged 3 to 6 years, were surveyed and 20.81% presented with some form of maxillary constriction. Normal occlusion was observed in 26.74% of the sample. According to da Silva Filho, the definition of a normal

relationship of the maxilla and mandible are: "1) The maxillary arch should entirely contain the mandibular arch, 2) The interarch sagittal relationship, as evaluated by the canines, should be Class I, in which the cusp tip of the maxillary canine lies between the mandibular canine and the primary first molar, and 3) The incisal relationship should assure positive overbite and overjet." Da Silva Filho also described posterior crossbites to be "characterized by a reverse transverse interarch relationship in response to a reduction in the transverse dimension of the maxillary arch."

Correction of dental crossbites is recommended in mixed dentition because it "eliminates functional shifts and wear on the erupted permanent teeth, and possibly dentoalveolar asymmetry" (Langberg et al., 2005). Correction is also important "to redirect the developing teeth into more normal positions, eliminate untoward temporomandibular joint positions and mandibular closure patterns, and make beneficial dentoskeletal changes during growth periods involving a reduced treatment complexity and time" (Bell et al., 1982). Haas et al., in 1980 wrote a review about the importance of rapid maxillary expansion. Haas states, "in dentofacial

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orthopedics, the width factor seems to be the most important, since with facial growth, the width dimension changes the least; it also stops growing the earliest." Haas gives six indications for rapid maxillary expansion: "1. Cases of real and relative maxillary deficiency-A real deficiency is characterized by compression of the maxilla, when compared with the rest of the facial bones and the mandible; the maxilla is definitely undersized. A relative deficiency exists when the maxilla appears to be of normal size when compared with adjacent craniofacial bones but the mandible is mildly or even moderately oversized. 2. Cases of nasal stenosis-They are usually characterized by full-time mouth breathing and a constricted nasal aperture with the conchae literally compressed against the septum. 3. All types of Class III cases-These would include, of course, the pseudo Class III, the dental Class III, and the surgical Class III. 4. The mature cleft palate patient. 5. Anteroposterior maxillary deficiency cases-These are cases with negative ANB angles, a negative point A to facial plane, or negative Wit analysis, which could benefit from maxillary protraction. 6. Selected arch length problems in a mature good morphogenetic skeletal pattern."

Diagnosis of a crossbite is performed in maximum intercuspation (da Silva et al., 2007). The most common type of crossbite is the functional unilateral posterior crossbite (da Silva et al., 2007). The etiology of maxillary constriction is environmental factors, genetic factors or a combination of both (Proffit WR et al., 2007; Al-Battikki et al., 2001). Genetic factors include cleft lip and palate patients. Environmental factors include mouth breathing attributed to nasal blockage and oral habits (Al-Battikki et al., 2001). Harvold et al., 1972, conducted a study to created narrow maxillary arches in Rhesus monkeys by converting them from nasal to obligatory oral respiration.

In adolescent patients, correction of maxillary constriction can be treated in three ways: (1) rapid expansion with a jackscrew device attached to the maxillary posterior teeth, at the rate of 0.5 to 1 mm/day; (2) slow expansion with the same device at the rate of approximately 1 mm per week; or (3) expansion with a device attached to bone screws or implants, so that the force is directly applied to the bone and there is no pressure against the teeth (Proffit WR et al, 2007). According to Isaacson et al in 1964, forces

created by rapid maxillary expansion appliances can reach 3-10 pounds. An important goal of these appliances is to achieve arch width to allow a proper and stable relationship of the maxilla and mandible (Bell et al., 1982). During the correction of maxillary constriction, there is greater movement at the level of the alveolar crest and less movement at the level of the palatal vault "presenting a triangular expansion pattern with the base near the incisors and the apex toward the nasal area" (Bell et al., 1982). Bell continued to describe the movements from the occlusal view: "the greatest opening of the midpalatal suture has been found anteriorly, with progressively less separation toward the posterior," and in the sagittal plane "a downward and forward displacment of the maxilla with opening of the bite."

Melsen et al, in 1975, conducted a study to analyze postnatal changes of the hard palate. They used conventional histologic and microradiographic means on autopsy material from thirty-three boys and twenty-seven girls aged 0 to 18 years. They report that "at birth the suture was broad and slightly sinuous and later it developed into a typical squamous suture." After the age of 13 to 14 years of age, the suture becomes serpentine

and constricts the connective tissue covering the lateral parts of the palate. After the age of 16 in girls and 18 in boys the transverse growth of the midpalatal suture ceased.

According to Starnbach et al., in 1966, like all craniofacial sutures, the mid-palatal suture becomes more tortuous and interdigitated with increasing age. There is an abnormal increase in the number of osteoblasts and osteoclasts present in the frontonasal complex. Also in the frontonasal complex, the tissue also becomes hypervascularized. The same observations occur in the maxillary-zygomatic suture, but are less intense. The zygomaticotemporal sutures show the least amount of activity.

Cleall et al., 1965, studied the sutures affected during rapid maxillary expansion on 6 female Macacus rhesus monkeys, ranging in age from thirty to forty months. The ages of the Macacus rhesus monkeys used in this study are equivalent to a seven to nine-year old human. Nembutal anesthesia was used to sedate the monkeys prior to experimentation. Maxillary and mandibular models were taken to determine the degree of orthodontic expansion of the maxillary dental arch. Frontal

cephalometric head plates were exposed to measure the effect that rapid maxillary expansion had on surrounding boney structures, the alveolar arch, and the angular changes in the inclination of the palatal shelves. Lateral cephalometric head plates were also used to measure before and after changes. Four monkeys were treated with rapid maxillary expansion, while the other two were controls, not treated with rapid maxillary expansion. The expansion appliances attached to the maxillary permanent first molars, and the first and second deciduous molars. An expansion screw was embedded in the midline of the acrylic of the expansion appliance. The first monkey sacrificed had 2 weeks of expansion for a total of 4 mm of expansion achieved. The remaining 3 monkeys had an additional 2 mm of expansion over a period of 12 weeks. After this period, another monkey was sacrificed. After a 3-month retention period, the third experimental animal was sacrificed. The fourth monkey had the appliance removed and they allowed 3 months without any retention. After this period, the fourth monkey was sacrificed. After sacrificing the monkeys, the maxillary complexes were then dissected and stored in ten percent neutral formalin. Radiographs were then taken in order to

evaluate the bony relationships. After the radiographs had been taken, the maxilla was cut transversly into blocks of 2.5 mm wide. These sections were then histologically analyzed to determine what happened during the respective treatments. When comparing the two controls, both showed similar sutural and bony morphology. Normal osteoblastic and osteoclastic activities were happening in the sutures of the controls. The first monkey, sacrificed after a 2 week period, showed that the midpalatal suture to be "dislocated leaving a bony defect filled with disorganized fibrous connective tissue and irregularly-positioned spicules of bone" (Cleall et al., 1965). Cephalometric examination showed widening of the midpalatal suture, and the teeth appeared to be tipped buccally, the roots palatal to the crowns of the maxillary teeth. The monkey sacrificed after three months of expansion also showed widening of the maxillary arch, but no increase in width of the nasal cavity was observed. The widened midpalatal suture was now filled by fibrous connective tissue containing numerous fibroblasts. Mineralized spicules were now projecting into the defect. As expected, an inflammatory response was observed, but much less than the monkey

sacrificed after two weeks. No interdigitations of the sutures were present. Osteoblasts now dominated the boney defect and there was marked attempt to fill the space created by rapid maxillary expansion. Reversal lines were present and confirm the attempt to fill the space and heal the boney defect. The monkey sacrificed after 3 months of expansion displayed less tipping of the teeth compared to the first two monkeys sacrificed. An occlusal film was taken, and it revealed now normal inclination of the maxillary teeth. Using this record also showed minor evidence of previous damage. The morphology of the midpalatal suture closely resembled the control's midpalatal sutures. The suture was now appearing to heal, but the adjacent bone and boney trabeculae were now very cellular. Remodeling was now apparent with the ratio of the osteoclastic and osteoblastic activity. The areas affected by rapid maxillary expansion were still disorganized and poorly mineralized compared to the control animals. Finally, the monkey subjected to expansion, retention, and then a 3 month post-retention period revealed, like the other experimental monkeys did, flattening and widening of the palate, but the widening and the flattening had persisted through the post-

retention period. The inclinations of the maxillary teeth were unaffected. The occlusal films revealed that the sutures now appeared well organized and histologically normal. There appeared no evidence of a breakdown of the repaired suture. The degree of mineralization of the midpalatal suture appeared indistinguishable from the two controls. Although, while the rhesus monkey provides a close approximation to human morphology, differences still exist. An example of one of these differences is the rhesus monkey has distinct and separate premaxilla, which articulates with maxillary bones. There is no distinct midpalatal suture as found in humans.

To accurately examine the forces produced by rapid expansion techniques, Isaacson et al., 1964, conducted a study that constructed and calibrated a force measuring system. One half on an expansion screw was embedded into acrylic, and the other half was soldered to one end of a stainless steel beam having two right angle bends. This appliance was then soldered to oversized bands on the teeth. The teeth used in the study were maxillary first permanent molars and first bicuspids (or stable deciduous molars). Activation of the expansion screw in the mouth was accompanied by deformation of the metal. The

deformations were then recorded and compared with deformations produced by known loads. Therefore, the magnitude of the appliance can be determined by using a force-measuring dynomometer. The study was conducted on five patients ranging from eight years six months to fifteen years six months. Four of the patients were female and one male. All patients presented with bilateral crossbites with some degree of maxillary constriction. The expansion screw was opened 0.8 mm for each complete revolution of the screw and each activation was 0.2 mm. A single activation of the expansion screw produced from about 3 to 10 pounds of force. A smaller load was recorded per activation for younger patients compared to older patients. This finding revealed that with increasing maturity and age, the greater the facial skeleton increases its resistance. Whether or not the midpalatal suture was open at the time of expansion did not significantly change the forces present. This study concluded that the major resistance to rapid maxillary expansion is not in the midpalalal suture but the remainder of the maxillary articulations.

The alveolar process is defined as "the parts of the maxilla and the mandible that form and support the

sockets of the teeth. The alveolar process develops in conjunction with the development and eruption of the teeth" (Lindhe et al., 2003). Orthodontic treatment relies on prolonged pressure applied to a tooth and the remodeling of bone surrounding the tooth. Bone is selectively removed and added depending on the amount, direction, and duration of pressure (Proffit WR et al., 2007). Experimental studies in animals (Steiner et al., 1981) have shown that when a tooth has a force applied in a direction towards and through the cortical plate, apposition of bone does not take place on the side of the cortical bone (Lindhe et al., 2003). After prolonged exposure of the tooth against the cortical plate, a dehiscence is created (Lindhe et al., 2003). Orthodontic treatment with lateral expansion may cause such a perforation through the cortical plate (Greenbaum et al., 1982).

In addition to effects of RME to bone, Langford et al., in 1982, conducted a study to assess the area of root surface resorption on extracted RME anchor premolar teeth from eighteen patients held in fixed retention for periods varying between 14 and 52 weeks. The roots of the teeth were examined via light microscopy and scanning

electron microscopy. Resorptive defects were found exclusively with cellular cementum. Langford found that areas of resorption present were extensive, but did get worse over time. Repair tissue increased with prolonged retention periods, up to a maximum of 53 weeks of retention in this study. This study explained, "the topographic findings suggest that strong relapse forces are probably dissipated after 3 months of retention." This study did not show any correlation between the period of RME, the length of retention, and the total area of resorption affecting the anchor teeth.

Garib et al., 2006, evaluated periodontal changes by means of computed tomography after rapid maxillary expansion (RME) with tooth-tissue-borne and tooth-borne expanders. The sample was comprised of 8 girls, 11-14 years old, with Class I or II malocclusions with unilateral or bilateral posterior crossbites. 4 girls were treated with tooth-tissue-borne Haas-type expanders, and 4 were treated tooth-borne Hyrax expanders. Both expanders were activated up to the full 7-mm capacity of the expansion screw. Spiral CT scans were taken before expansion and after the 3-month retention period when the expander was removed. One-millimeter thick axial

sections were exposed parallel to the palatal plane, and multiplanar reconstruction was used to measure buccal and lingual bone plate thickness and buccal alveolar bone crest level by means of the computerized method. They found that RME reduced the buccal bone plate thickness of supporting teeth 0.6 to 0.9 mm and increased the lingual bone plate thickness 0.8 to 1.3 mm. Dehiscences were found on teeth attached to the expander on the buccal aspect. They concluded that their finding is due to the absence of correspondent compensatory bone apposition under the buccal periosteum. However, their sample was quite small. This is mainly because they used a spiral CT machine, which has a high effective radiation dose. A CBCT produces a much lower effective radiation dose and can still produce clear images of highly contrasting structures (Scarf et al., 2006; Sukovic et al.; 2003, Ziegler et al, 2002). They also were not able to show any long-term data with their second CBCT image taken just 3 months after the expanders were removed. They evaluated intra-examiner reliability using questionable methodology. They did not report the typical intraclass correlation.

Rungcharassaeng et al., 2007, used cone-beam computed tomography (CBCT) images to determine the factors that might affect buccal bone changes of maxillary posterior teeth after rapid maxillary expansion (RME). Thirty consecutive patients (17 boys, 13 girls; mean age, 13.8 ± 1.7 years) who required RME as part of their orthodontic treatment had a pre-rapid maxillary expansion (T0) and post-rapid maxillary expansion (T1) CBCT taken. The post-rapid maxillary expansion CBCT was obtained within 3 months after the end of activation. Measurements taken include interdental distance, interdental angle (IA), buccal bone thickness (BBT), and buccal marginal bone levels (BMBL) of the first premolars (P1), the second premolar (P2), and the first molar (M1). For M1, only BMBL and BBT of the mesiobuccal root were evaluated because it is usually more prominent and likely to exhibit more changes than the distobuccal root (Garib et al., 2006). They used the Wilcoxon signed rank test and found the changes in BBT and BMBL were statistically significantly less in P2 than in P1 and M1. The findings in this study are important, but T1 is within three months after the end of activation and still may be considered the initial effects of RME.

Starnbach et al, in 1966, studied maxillary expansion in five Macaca rhesus monkeys. They varied slightly in development, but were equivalent to humans, seven to nine years old. One monkey served as a control with no treatment. The remaining four were treated with rapid expansion of the maxillary palate using a split acrylic palate with a central expansion screw. The appliance was anchored with integral bands cemented to the first and second deciduous molars, and the first permanent molar. The first experimental animal was sacrificed after two weeks following 4 mm of expansion, which was measured from molar cusp to molar cusp. The second experimental animal was sacrificed after 6 mm of expansion, which was completed after 3 months. The third experimental animal was sacrificed after 6 mm of expansion, which took 3 months plus a 3 month retention period. In the fourth experimental animal, 6 mm of expansion was completed in 3 months, followed by 3 months of retention, followed by an additional 3 months postretention. After being sacrificed, the maxillae were sectioned transversly into blocks, approximately two and one-half mm thick. They demonstrated, histologically, the incidence of buccal bone resorption of posterior

teeth after 2 weeks of orthodontic expansion. "Periodontal membranes of the teeth involved with expansion were found to be stretched on the palatal aspect." "The periodontal membranes were observed to be disorganized and to contain cell-free zones on the buccal sides." "The alveolar bone surface was irregular and scalloped and showed many areas of bone resorption." After 6 mm of expansion in 3 months, "the periodontal membrane fibers and cellular elements were less severely disrupted than observed in the first experimental animal." "After 3 months of expansion, the dental supporting structures had reacted and were adjusting to the expansion forces." After 3 months of retention, there study displayed "much evidence of recent alvoeloar bone formation" and "showed progressive improvement in the tissues of the supporting structures." "Almost normal fiber distribution and cell population, while the alveolar bone was only slightly more irregular than normal." 3 months of postretention, "showed continued adjustment toward 'near normal' dental supporting structures." This study agrees with Timms and Moss et al., 1971, who found evidence of a reversal line well within the buccal bone, and also bone deposition one year

after RME therapy. The reversal line demarcates the cessation of osteoclast activity from the commencement of osteoblast activity at a remodeling site in bone. It is a seam between segments of bone that are formed at different times. This study also gives a description of the changes that occur in the facial sutures as a result of expansion. The anterior half of the midpalatal suture opened more than posterior at a ratio of 3:2, sometimes as great as 2:1.

Greenbaum et al., 1982, examined sixty-one post-orthodontic patients to determine the effects of palatal expansion therapy on the periodontal supporting structures located at the buccal aspects on the maxillary first permanent molars. Twenty-eight patients were treated with rapid maxillary expansion technique using a tissue-borne, fixed, split acrylic appliance. Thirty-three underwent slow palatal expansion with a quad-helix. The mean increases in intermolar width were 4.6 mm and 4.3 mm, respectively. Twenty-eight patients were treated with light wire edge-wise technique without palatal expansion as the control. Four periodontal parameters were examined, including level of marginal alveolar bone height, attachment levels (from CEJ), probing depths, and

width of keratinized gingival. The results demonstrated that there were minimal differences in periodontal condition when compared to the control group. The average attachment levels being 0.65 mm, 0.36 mm, and 0.51 mm in the rapid expansion, slow expansion, and control groups, respectively. However, they did not measure these periodontal parameters before orthodontic treatment on any of the groups. Individual measurements could have been measured, before and after orthodontic treatment, including palatal expansion. There seemed to be a wide range of time between when expansion was completed and when the measurements were taken. According to Starnbach, a significant amount of healing takes place after rapid maxillary expansion is performed. Without a surgical flap or the use of a CBCT, it would be difficult to assess dehiscences or fenestrations.

Rupprecht et al., 2001, investigated the prevalence, distribution, and features of alveolar dehiscences and fenestrations in 146 modern American skulls. They found that the maxillary first molars were most often affected by fenestrations (37%). They describe that a possible etiologic factor could be orthodontic tooth movement.

Garrett et al., 2008, used a CBCT to quantitatively evaluate and compare skeletal expansion and alveolar tipping of the maxilla at the maxillary canine, first premolar, second premolar, and first molar after RME. Thirty consecutive patients (17 boys, 13 girls) who required rapid maxillary expansion were studied. A CBCT was taken before orthodontic treatment and post-rapid maxillary expansion CBCT images within 3 months after the end of appliance activation. Their results indicated that expansion of the maxilla had a triangular pattern with a wider base in the anterior region, accounting for 55% of total expansion at the first premolar, 45% at the second premolar, and 38% at the first molar. Alveolar bending or tipping accounted for 6% of total expansion at the first premolar, 9% at the second premolar, and 13% at the first molar. Orthodontic tipping accounted for the rest of the expansion with 39% at the first premolar, 46% at the second premolar, and 49% at the first molar. These results indicate that expansion at the first molars is more dental rather than skeletal, which would cause a higher incidence of dehiscences (Lindhe et al., 2003). This agrees with Betts et al., 1995, that excessive expansion carries the risk of fenestration of premolar

and molar roots through the alveolar bone. Also, that there is an increasing risk of fenestration beyond 3 mm of transverse tooth movement. However, Garrett et al's method for measuring expansion at the first molar region is not reliable since their point of reference is an estimate between three roots and not a distinct point. They compared their pre-treatment CBCT to a CBCT image taken within 3 months of after the end of appliance activation. Again, Starnbach et al (1966) observed further bone formation post 3 months of retention of expansion. It would be interesting to see the change in bone thickness after the completion of orthodontic treatment.

Developed in the late 1990's, cone-beam computed tomography (CBCT) scanners with lower radiation dose and lower costs have been useful for 3D dental imaging and craniofacial applications (Mozzo et al., 1998; Mah et al., 2004; Cevidanes et al., 2007). The 3D imaging allows measurements of vertical, transverse, and anteroposterior dimension of maxilla and mandible.

Baumgaertel et al., in 2007, completed a study to determine the accuracy of measurements off of a DICOM image from a CBCT machine. They used 30 human skulls that

were scanned with dental CBCT. 3-dimensional reconstructions of the dentitions were generated. Ten measurements (including overbite, overjet, maxillary and mandibular intermolar and intercanine widths, arch length available, and arch length required) were made directly on the skulls using digital calipers and were also made with commercially available software. Both measurements were highly reliable ($r>0.90$). The CBCT measurements slightly underestimate the actual anatomic measurements. The conclusions from this study are that the CBCT volumes can be used for quantitative analysis.

Ballrick et al., in 2008, conducted a study to evaluate images produced by a commercially available CBCT machine for measurement and spatial relation. More specifically they wanted to determine the accuracy of the ability to separate 2 objects in close proximity for all settings and in all dimensions. The study was conducted by using a phantom containing 0.3 mm diameter chromium metal markers approximately 5 mm apart in 3 planes of space. This was then used to analyze distortion and measure accuracy. All 12 commercially available settings were used to scan the phantom in the CBCT machine. The distance between the markers was measured 3 times on 3-

dimensional images by using a Digital Imaging and Communications in Medicine (DICOM) viewer. The phantom was also directly measured using digital calipers. Thirty evaluators analyzed the images produced by the DICOM viewer using an assigned resolution from 0.2 to 1.6 mm according to the separation of the lines. The result suggest, even with a statistically significant difference ($P<0.01$) between the measurements taken from the DICOM viewer and the direct measurements taken by the phantom, that the difference is not clinically significant for most applications. The conclusion from this study is that the CBCT machine has clinically accurate measurements and acceptable resolution.

Leung et al., in 2010, conducted an in vivo study to assess the accuracy and reliability of using a CBCT on human skulls to diagnose naturally occurring fenestrations and bony dehiscences. Measurements were made on thirteen dry human skulls with 334 teeth from the CBCT image and were compared with direct measurements. The mean differences of the measurements attained from the CBCT and direct measurement from the skull were 0.4 ± 0.3 mm for the cementoenamel junction and 0.6 ± 0.8 mm for the bone margin.

LIT REVIEW REFERENCES

Al-Battikki R. Rapid maxillary expansion: Review of literature. Saudi Dental Journal, Vol. 13 No. 3 September-December 2001.

Ballrick JW, Palomo JM, Ruch E, Amberman BD, Hans MG. Image distortion and spatial resolution of a commercially available cone-beam computed tomography machine. Techno Bytes 2008.11.025:573-582.

Baumgaertel S, Palomo JM, Palomo L, Hans MG. Reliability and accuracy of cone-beam computed tomography dental measurements. Am. J. Ortho. 2007.09.016: 19-25.

Bell, RA. A review of maxillary expansion in relation to rate of expansion and patient's age. Am. J. Orthod. 1982;81:32-37.

Betts NJ, Vanarsdall RJ, Barber HD, el al. Diagnosis and treatment of transverse maxillary deficiency. Int J Adult Orthod Orthogn Surg 10:75-96, 1995.

Bjork, A., and Skieller, V.: Postnatal growth and development of the maxillary complex. In: Factors Affecting the Growth of the Midface. McNamara, J.A., Jr., (ed.), Ann Arbor, Center for Human Growth and Development, 1976, 399p. (pp. 61-99).

Cleall JF, Bayne DI, Posen JM, Subtelny JD. Expansion Of The Midpalatal Suture In The Monkey. Angle Orthod 1965;35:23-35.

da Silva Filho. Epidemiology of Posterior crossbite in the Primary Dentition. The Journal of Clinical Pediatric Dentistry, Volume 32, Number 1/2007.

Garib DG. Periodontal effects of rapid maxillary expansion with tooth-tissue-borne and tooth-borne expanders- A computed tomography evaluation. Am J Orthod Dentofacial Orthop. 2006 Jun;129(6):749-58.

Garrett BJ. Skeletal effects to the maxilla after rapid maxillary expansion assessed with cone-beam computed

tomography. Am J Orthod Dentofacial Orthop. 2008 Jul;134(1):8-9.

Greenbaum KR, Zachrisson BU. The effect of palatal expansion therapy on the periodontal supporting tissues. Am J Orthod. 1982 Jan;81 (1):12-21.

HAAS AJ. Long-Term Posttreatment Evaluation of Rapid maxillary expansion. Angle Orthod. 1980 Jul;50(3):189-217.

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

Isaacson RJ, Ingram AH. Forces produced by rapid maxillary expansion. Angle Orthod 1964;34:261-270.

Langberg BJ, Arai K, Miner RM. Transverse skeletal and dental asymmetry in adults with unilateral lingual posterior crossbite. Am J Orthod Dento Orthop 127:6-15, 2005.

Langford, SR. Root surface resorption, repair, and periodontal attachment following rapid maxillary expansion in man. Am. J. Orthod. 1982;81:32: 108-115.

Langford, SR. Root resorption extremes resulting from clinical RME. Am. J. Orthod. 1982;81:32:371-377.

Lekhom U, Zarb GA. Ptient selection and preparation. In: Branemark Pi, Zarb GA, Albrektsson T, editors. Tissue-integrated prosthesis: osseointegration in clinical dentistry. Chicago, IL: Quintessence Publishing, 1985, 199-209.

Leung CC, Palomo L, Griffith R, Hans MG. Accuracy and reliability of cone-beam computed tomography for measuring alveolar bone height and detecting bony dehiscences and fenestrations. Am J Orthod Dentofacial Orthop. 2010 Apr;137(4 Suppl):S109-19.

Lindhe J. Clinical Periodontalogy and Implant Dentistry. 4th ed. Blackwell Munksgaard; 2003. pgs: 744-778.

Melsen B. Palatal growth studied on human autopsy material. Am J Orthod 1975;68:42-54.

Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. Nakajima. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. Eur Radiol. 1998;8(9):1558-64.

Proffit WR, Fields HW. Contemporary Orthodontics. 4th ed. Mosby; 2007. pgs. 4-43, 100, 331

Rungcharssaeng K. Factors affecting buccal bone changes of maxillary posterior teeth after rapid maxillary expansion. Am J Orthod Dentofacial Orthop. 2007 Oct;132(4):428.e1-8.

Rupprecht RD. Prevalence of Dehiscences and Fenestations in Modern American Skulls. J Periodontol. 2001 Jun;72(6):722-9.

Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. J Can Dent Assoc 2006;72:75-80.

Starnbach H. Facioskeletal and dental changes resulting from rapid maxillary expansion. Angle Orthod. 1966 Apr;36(2):152-64.

Steiner, G.G., Pearson, J.K. & Ainmao, J. (1981). Changes of the marginal periodontium as a result of labial tooth movement in monkeys. Journal of Periodontology. 52, 314-320.

Sukovic P. Cone beam computed tomography in craniofacial imaging. Orthod Craniofac Res 2003;6(Suppl 1):31-6.

Timms, Moss. A histological investigation into the effects of rapid maxillary expansion on the teeth and their supporting tissues. Trans Eur Orthod Soc 1971; 263-71.

Ziegler CM, Woertche R, Brief J, Hassfeld S. Clinical indications for digital volume tomography in oral and maxillofacial surgery. DMFR 2002;31:126-30.

STATEMENT OF THESIS

This study has two objectives: 1) To detect if there is a difference in bone thickness buccal and palatal to the permanent maxillary first molars between adolescent patients treated with rapid maxillary expansion and adolescent patients treated without expansion following orthodontics. 2) To relate bone thickness buccal and palatal to the permanent maxillary first molar roots before and after orthodontic treatment to the amount of expansion that occurred due to orthodontic treatment with rapid maxillary expansion and without expansion.

It is hypothesized that there is no difference in the bone thickness buccal and palatal to the permanent maxillary first molars following orthodontic treatment with adolescent patients treated with rapid maxillary expansion and adolescent patients without expansion. It is also hypothesized that there is no correlation between the change in the thickness of bone buccal and palatal to permanent maxillary first molars to the change in intermolar width after the completion of orthodontic treatment with rapid maxillary expansion in adolescent patients.

Alveolar Bone Thickness after Orthodontic Treatment with and without Rapid Maxillary Expansion

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Objectives: To detect a difference in bone thickness supporting the maxillary first molars between patients treated with rapid maxillary expansion (RME) and patients treated without expansion following orthodontics. To relate bone thickness supporting the maxillary first molars to the amount of expansion. **Methods:** The RME group consisted of 17 male and 15 female patients, with a mean age of 13.67 ± 1.25 years. The non-expansion group consisted of 17 male and 15 female, with a mean age of 13.82 ± 0.67 years. CBCT images were used to measure intermolar width and bone thickness supporting the maxillary first molars. **Results:** Subjects with RME had a mean intermolar expansion of 3.05 mm ± 2.10 mm, ($P < 0.001$). The mean thickness of bone on the mesiobuccal significantly decreased from 1.46 mm to 1.18 mm ($P < 0.001$). There was no correlation between the change in intermolar width and change in mesiobuccal bone thickness of the maxillary first molars. **Conclusions:** There was a statistically significant decrease of bone thickness on the mesiobuccal surface of the maxillary first molars after orthodontic treatment of patients treated with RME compared to patients treated without expansion. However, the difference was not considered clinically significant.

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INTRODUCTION

Having a full understanding of what happens to the periodontal supporting tissues during orthodontic treatment should be a vital part of our knowledge. "Before any kind of orthodontic therapy is started, it is important to check the buccolingual thickness of the bone and soft tissues on the pressure side of all teeth, which are to be moved." [1] "Maintaining a healthy periodontal status in orthodontic patients is a perennial and ubiquitous challenge to most orthodontists." [2] Both components of the periodontium can be affected by orthodontics adversely. These are the soft tissue "gingival unit" around the crown, and the "attachment apparatus" that connects the root to bone. [2]

The maxilla is formed through intramembranous ossification and is composed of trabecular bone surrounded by cortical bone[3]. The alveolar process is defined as "the parts of the maxilla and the mandible that form and support the sockets of the teeth. The alveolar process develops in conjunction with the development and eruption of the teeth." [1] Orthodontic treatment relies on prolonged pressure applied to a tooth and the remodeling of bone surrounding the tooth. Bone is selectively removed and added depending on the amount, direction, and duration of pressure[4]. Experimental studies in animals[5,6] have shown that when a tooth has a force applied in a direction towards and through the cortical plate, apposition of bone does not take

place on the side of the cortical bone. After prolonged exposure of the tooth against the cortical plate, a dehiscence is created.[1] Orthodontic treatment with lateral expansion may cause such a perforation through the cortical plate[7].

Starnbach et al[6], in 1966 studied rapid maxillary expansion (RME) in 5 Macaca rhesus monkeys. They demonstrated, histologically, the incidence of buccal bone resorption of posterior teeth after 2 weeks of orthodontic expansion. Their studied continued with observing bone formation and healing of the periodontal structures after 3 months of retention and further healing 3 months later. This study agrees with Timms and Moss et al[8], in 1971, who found evidence of a reversal line well within the buccal bone and also bone deposition one year after RME therapy. The reversal line demarcates the cessation of osteoclast activity from the commencement of osteoblast activity at a remodeling site in bone.

Rungcharassaeng et al[9], in 2007 used cone-beam computed tomography (CBCT) images to determine the factors that might affect buccal bone changes of maxillary posterior teeth after RME. Thirty consecutive patients (17 boys, 13 girls; mean age, 13.8 ± 1.7 years) who required RME as part of their orthodontic treatment had a pre-rapid maxillary expansion (T0) and post-rapid maxillary expansion (T1) CBCT taken. They found that RME reduced the buccal bone plate thickness of supporting teeth 1.24 mm. The findings in this study are important, but T1 is within three months after the end of activation and still may be considered the initial effects of RME.

Garib et al[10], in 2006, evaluated periodontal changes by means of computed tomography after RME with tooth-tissue-borne and tooth-borne expanders. Spiral CT scans were taken before expansion and after the 3-month retention period when the expander was removed. One-millimeter thick axial sections were exposed to the palatal plane, and multiplanar reconstruction was used to measure buccal and lingual bone plate thickness and buccal alveolar bone crest level by means of the computerized method. They found that RME reduced the buccal bone plate thickness of supporting teeth by 0.7 mm. Dehiscences were found on teeth attached to the expander on the buccal aspect. They were also not able to show any long-term data with their second CBCT image taken just 3 months after the expanders were removed.

Studies have been performed using a CBCT or CT to measure the effects of RME but long-term data is needed to understand if healing of the components of the periodontium continue to heal.

The purpose of this study is to: 1) To detect if there is a difference in bone thickness buccal and palatal to the maxillary first molars between adolescent patients treated with rapid maxillary expansion and adolescent patients treated without expansion following orthodontics. 2) To relate bone thickness buccal and palatal to the maxillary first molar roots before and after orthodontic treatment to the amount of expansion that occurred due to orthodontic treatment with rapid maxillary expansion and without expansion.

It is hypothesized that there is no difference in the bone thickness buccal and palatal to the permanent maxillary first molars following orthodontic treatment with adolescent patients treated with rapid maxillary expansion and adolescent patients without expansion. It is also hypothesized that there is no correlation between the change in the thickness of bone buccal and palatal to permanent maxillary first molars to the change in intermolar width after the completion of orthodontic treatment with rapid maxillary expansion.

The null hypothesis for the first objective is stated as, "there is no difference in the bone thickness buccal and palatal to the permanent maxillary first molars following orthodontic treatment with adolescent patients treated with rapid maxillary expansion and adolescent patients without expansion." The null hypothesis for the second objective is stated as, "there is no correlation between the change in the thickness of bone buccal and palatal to permanent maxillary first molars to the change in intermolar width after the completion of orthodontic treatment with rapid maxillary expansion."

MATERIAL AND METHODS

This is a case control study approved by the Case Western Reserve University Institutional Review Board (IRB). Subjects were selected from a sample of patients presenting to the dental school for comprehensive orthodontic treatment in the graduate clinic. Data were derived from pretreatment and post-treatment Cone Beam Computed Tomography (CBCT) scans (CB MercuRay™, Hitachi Medical Systems America Co. – Twinsburg, OH). All scans were taken in the Craniofacial Imaging Center at Case School of Dental Medicine during routine records appointments using the 2mA setting and the largest field of view (0.38 voxel size). A total of 431 pretreatment patient records consisting of CBCT scans, photographs and medical history forms were available. Using an expected effect size of 0.6 mm[11], a standard deviation of 0.76 mm[9], a two-tailed α of 0.05, and β of 0.10, a sample size of 33 was required per group when using a t test to compare means of continuous variables. Using a confidence level of 95%, a desired total width of 0.6[11] and standard deviation of 0.76 mm[9], a sample size of 25 was required for a descriptive study of continuous variables. All eligible subjects were included in the study

The experimental group was selected on the following criteria.

Selection criteria:

1. Age between 11 and 18 years old at the time of the initial records.

2. Either a 2 banded hyrax, 4 banded hyrax, Haas expander, or bonded expander was used during orthodontic treatment.

3. The expanders were turned until the clinician approved the amount of expansion.

4. After active turning was completed, the expander was locked and retained for the amount of time that the clinician approved.

5. Both maxillary first molars were present and erupted into occlusion determined from CBCT.

6. Landmarks (height of contour of maxillary permanent first molar roots, buccal & palatal cortical plate, and root canals) of measured teeth were clearly visible on the CBCT scan.

7. Agreed to orthodontic treatment in the Department of Orthodontics at Case Western Reserve University.

Exclusion criteria:

1. No extracted maxillary permanent teeth due to crowding, trauma or decay determined from CBCT.

2. No supernumeraries or congenitally missing maxillary permanent teeth determined from CBCT.

3. No severe rotation ($\geq$ 90 degrees) of maxillary permanent first molars determined from CBCT.

4. No previous endodontic treatment performed on maxillary permanent first molars determined from CBCT.

5. No craniofacial deformities (ex. cleft lip and palate).

The control group was selected on the following criteria.

Selection criteria:

1. The age at the time of initial records, age at the time of final records, and time in treatment of the control group must all be within one standard deviation of the mean age at the time of initial records, mean age at the time of final records, and mean time in treatment of the

experimental group respectively.

2. An increase of intermolar width was not attempted with a rapid maxillary expansion appliance nor with arch wires.

3. Both maxillary permanent first molars were present and erupted into occlusion determined from CBCT.

4. Landmarks (height of contour of maxillary first molar roots, buccal & palatal cortical plate, and root canals) of measured teeth were clearly visible on the CBCT scan.

5. Agreed to orthodontic treatment in the Department of Orthodontics at Case Western Reserve University.

Exclusion criteria:

1. More than 1.50 mm of intermolar width increase at the level of the pulpal furcation at the palatal root canal.

2. No extracted maxillary permanent teeth due to crowding, trauma or decay determined from CBCT.

3. No supernumeraries or congenitally missing maxillary permanent teeth determined from CBCT.

4. No severe rotation ($\geq$ 90 degrees) of maxillary permanent first molars determined from CBCT.

5. No previous endodontic treatment performed on maxillary permanent first molars determined from CBCT.

6. No craniofacial deformities (ex. cleft lip and palate)

Thirty-two subjects met the selection criteria that required rapid maxillary expansion as part of their comprehensive orthodontic treatment. To provide a similar control group, thirty-two similar patients met the selection criteria that were treated with comprehensive orthodontics without rapid maxillary expansion or without expansion ($\leq$1.50 mm) with an arch wire. The rapid maxillary expansion appliances

used during treatment consisted of either a 2-banded hyrax (supported by bilateral permanent first molars with expansion arms extending to first premolars), 4-banded hyrax (supported by bilateral permanent first molars and first premolars), 4 banded Haas (supported by bilateral permanent first molars and first premolars with acrylic shelves against the palatal shelves), or bonded expander (supported by a wire frame surrounded in acrylic covering the palate, buccal, occlusal, lingual surfaces of the permanent first molars, second premolars, and first premolars.

Permanent maxillary first molars were the focus of our study due to the following reasons: 1) Around the age of 12, the maxillary first molars are fully erupted. 2) Maxillary first molars erupt in the center of the alveolus without being blocked out. 3) Most rapid maxillary expander appliances attach to maxillary first molars. Rupprecht et al. [12], 2001, investigated the prevalence, distribution, and features of alveolar dehiscences and fenestrations in 146 modern American skulls. They found that the maxillary first molars were most often affected by fenestrations (37%). They describe that a possible etiologic factor could be orthodontic tooth movement.

In the rapid maxillary expansion group, there consisted 17 males and 15 females with the average age of 13.67 years (± 1.25 years) at the time of initial records and the average treatment time of 25.22 months (± 4.41 months). In the group treated without expansion, there consisted 17 males and 15 females with the average age of 13.82 (± 0.67 years) at the time of initial records and the average treatment time of 24.62 months (± 1.58 months). Final records were taken after orthodontic

treatment was completed and all appliances were removed. Demographics are presented in Table I.

A single operator collected the data. Radiographic data was constructed from CBCT images. The DICOM (Digital Imaging and Communications in Medicine) images were assessed with OnDemand 3D software (CyberMed, Version 1.2) and was used to measure intermolar width and thickness of bone buccal and palatal to the right (tooth #3) and left (tooth #14) permanent maxillary first molars. Each slice and volume image was stored as a jpeg image, and was labeled using a patient identifier. Initial and final 8 inch Cone Beam Computed Tomography (CBCT) scans were taken with the settings of 2 mA and 120 kVp. Demographic information was collected from each patient's record and included gender, age at start of treatment (in years), treatment duration (in months), type of appliance, activation time (in weeks), retention time (in weeks, from locking the expander to its removal), rate of turning (.25 mm per turn), amount of total turns, and teeth involved in a crossbite. Microsoft Excel (Version 12.1.9) was used to record and manage the data obtained.

Method of Intermolar Width and Thickness of Bone Buccal and Palatal to the Permanent Maxillary First Molars Measurements (Figures 1-6)

Slice thickness will be set default at 0.38 mm as a standard voxel height. Intermolar width and thickness of bone buccal and palatal to the permanent maxillary first molars was measured from the initial, before orthodontic treatment, and final, after orthodontic treatment, CBCT DICOM image for each subject. The data was obtained using the following steps:

1. In the axial view, the sagittal plane was set parallel to the palatal plane (ANS and PNS). (Figure 1)

2. In the sagittal view, the axial plane was set parallel to the palatal plane (ANS and PNS). (Figure 2)

3. In the coronal view, the axial plane was set parallel to the zygomatic arches directly above the right (tooth #3) permanent maxillary first molar palatal root canal. (Figure 3)

4. The axial plane was first adjusted to the level of the maxillary right molar pulpal furcation. (Figure 4a,b,c)

    a. The level of the pulpal furcation is defined as the furcation entrance. The furcation entrance is the "transitional area between the undivided and the divided part of the root." [1] Using CBCT to study the pulpal furcation, the axial plane is at the level just apical to the pulpal chamber and just coronal to the root furcation. It is the axial plane at the level just when three pulpal chambers can be distinguished from one another.

5. The bone thickness was measured, at the height of contour, buccal to the right first molar mesiobuccal and distobuccal roots. The bone thickness was measured, at the height of contour, palatal to the right maxillary first molar palatal root. (Figure 5a)

6. The axial plane was then set at the level of the permanent maxillary left first molar pulpal furcation and the bone thickness was measured, at the height of contour, buccal to the left first molar mesiobuccal and distobuccal roots. The bone thickness was measured, at the height of

contour, lingual to the left maxillary first molar palatal root. (Figure 5b)

7. When tooth rotations were present, the thickness of the bone plate was measured, at the height of contour, where the root was closer to the external contour of the alveolar ridge.

8. In the coronal plane, the axial plane was rotated until both, tooth #3 and tooth #14's pulpal furcations were visible in the axial plane.

9. The intermolar width was measured from the center of the mesiobuccal pulpal chamber, distobuccal pulpal chamber, and palatal pulpal chamber. If multiple canals were present in the mesiobuccal and distobuccal roots, measurements were taken from the most buccal pulpal chamber. If multiple canals were present in the palatal root chamber, the most palatal pulpal chamber was measured. (Figure 6)

Statistical analysis

Means, standard deviations, and ranges were calculated for each parameter. Paired t-tests were used to analyze bone thickness and intermolar widths of subjects before and after orthodontic treatment. Differences between the rapid maxillary expansion (experimental) and non-expansion groups (control) were tested with un-paired t-tests. A Pearson correlation was used to evaluate the relationship between the change in bone thickness and the change in intermolar width. Measurements were repeated after a three-week interval on 15 random initial and final CBCT scans from the control group and 15 random initial and final CBCT scans from the experimental group. These 30 subjects were chosen randomly, using a random number generator. The intraclass correlation (r^2) was used to assess reliability of all continuous measurements. All statistics were calculated using the Statistical Package for the Social Sciences (SPSS 17.0, Inc. – Chicago, IL).

RESULTS

Demographics

The final sample consisted of sixty-four subjects treated with comprehensive orthodontics. The overwhelming majority of subjects were Caucasoid (n=54) with seven Negroid, and two Mongoloid subjects. 32 subjects, 17 males and 15 females, were treated without expansion. The average age of the non-expansion group was 13.82 ± 0.67 years. 32 subjects, 17 males and 15 females, were treated with a rapid maxillary expansion appliance. The average age of the rapid maxillary expansion group was 13.62 ± 1.25 years. Sixteen subjects were treated with either a 2-banded or a 4-banded hyrax, eight subjects were treated with a Haas expander, and eight subjects were treated with a bonded expander. The average expansion, activation time, rate of turning, retention time, and treatment time were 3.05 ± 2.10 mm, 7.71 ± 4.93 weeks, 1.03 ± 0.30 (.25mm per turn) turns per day, 21.12 ± 6.62 weeks, and 25.22 ± 4.41 months, respectively. The average treatment time for the patients treated with comprehensive orthodontics without expansion was 24.62 ± 1.58 months. A descriptive summary of anthropological group, gender, age at initial and final records, treatment time and expander information is shown in Table I.

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Data for right and left sides were collected separately. A preliminary t-test showed no differences between the measurements taken on tooth #3 and tooth #14, so data from the right and left of each subject were combined for subsequent analyses.

Subjects with rapid maxillary expansion had, on average, 3.05 mm ± 2.10 mm ($P < 0.001$) of intermolar expansion measured at the level of the pulpal furcation at the palatal root canal. Intermolar width change ranged from 0.40 mm to 7.80 mm. For these subjects, the thickness of bone on the mesiobuccal decreased on average from 1.46 mm to 1.18 mm ($P < 0.001$). The thickness of bone on the distobuccal and palatal of the first molars decreased but the changes of either were not statistically significant. On average, the intermolar width change was greater between the mesiobuccal canals (Table II).

Subjects treated without expansion had, on average, 0.19 mm ± 0.90 mm of intermolar expansion measured at the level of the pulpal furcation at the palatal root canal. The amount of expansion was not statistically significant. Intermolar width change ranged from -2.20 mm to 1.50 mm. The changes of the thickness of bone around the maxillary first molars were not statistically significant. On average, the intermolar width change was greater between the mesiobuccal canals (Table II).

When comparing subjects treated with expansion and subjects treated without expansion, the only significant difference between the two groups before treatment was the intermolar width from all three canals ($P \leq 0.001$). After orthodontic treatment, there was not a significant difference between intermolar widths, only the thickness in bone. The mesiobuccal bone of the expansion group had a statistically

significant difference ($P \leq 0.001$) when compared to the control group. On average, patients without expansion had 0.37 mm thicker bone mesiobuccal to the maxillary first molar mesiobuccal root at the level of the pulpal furcation after orthodontic treatment was completed (Table II) compared to the patients with expansion. The rapid maxillary expansion group, on average, had a decrease of 0.28 ± 0.65 mm (initial: 1.46 mm ± 0.48 mm; final: 1.18 ± 0.64 mm). The non-expansion group, on average, had a decrease of 0.07 ± 0.54 mm (initial: 1.62 ± 0.54 mm; final: 1.55 ± 0.62 mm).

In our study, there were 30 females and 32 males. At time 1, the only significant difference was the mesiobuccal intermolar width. The males mesiobuccal intermolar width was 1.63 mm wider ($P<0.05$). At time 2, all three intermolar widths of the males were wider ($P<0.05$). There was no significant bone thickness difference between males and females at time 1 or time 2.

26 patients initially presented with either an anterior or posterior crossbite. 38 patients presented without an anterior or posterior crossbite. At time 1, patients with a crossbite had significantly narrower intermolar arch width between the mesiobuccal and distobuccal roots of 2.18 mm ($P<0.05$) and 2.14 ($P<0.05$), respectively. There was no significant difference in bone thickness at time 1. At time 2, patients that presented with an initial crossbite had 0.37 mm ($P<0.001$) less bone on the mesiobuccal of the maxillary first permanent molar. There was no significant difference in intermolar width at time 2.

Using a Pearson correlation coefficient, there was a weak correlation between the change in intermolar width and change in bone thickness buccal or palatal to the maxillary first molars with patients that were treated with rapid maxillary expansion.

Reliability

A single operator collected all measurements. Three weeks after the initial measurements, fifteen subjects from the rapid maxillary expansion group and fifteen subjects from the non-expansion group were randomly selected for repeat measurements using a random number generator. The intraclass correlation values ranged from .90 to .99 for all measurements taken (see Table II).

DISCUSSION

The purposes of this study were to use a CBCT to 1) To detect if there is a difference in bone thickness buccal and palatal to the permanent maxillary first molars between adolescent patients treated with rapid maxillary expansion and adolescent patients treated without expansion following orthodontics. 2) To relate bone thickness buccal and palatal to the permanent maxillary first molar roots before and after orthodontic treatment to the amount of expansion that occurred due to orthodontic treatment with rapid maxillary expansion and without expansion. Using the methods described, the intraclass correlation coefficient ranged from .90 to .99 for all measurements taken.

Cone Beam Computed Tomography has proven to be a powerful tool to perform research and orthodontic diagnosis[11,13,14,15,16,17]. According to Ballrick et al[13], CBCT can be used to make clinically accurate measurements and has acceptable resolution. Previous studies have looked at the periodontal apparatus involving maxillary molars[9, 10,18]. Most have a limited sample size and study the effects of rapid maxillary expansion soon after the expansion appliance had been removed. These studies show a significant decrease in buccal bone and increased palatal bone supporting the maxillary first molars. The immediate effects of rapid maxillary expansion are studied and the possible long-term accommodation of the periodontal structures is not observed. In our study, initial and final records are analyzed.

Starnbach et al[6], in 1966 demonstrated, histologically, the incidence of buccal bone resorption of posterior teeth after 2 weeks of rapid maxillary expansion. Their studied continued with observing bone formation after 3 months of retention and further healing 3 months later. This study agrees with Timms and Moss et al[8], 1971, who found evidence of a reversal line well within the buccal bone and also bone deposition one year after RME therapy.

Our study evaluated the permanent maxillary first molars by measuring the intermolar width and bone thickness surrounding these teeth. The intermolar width was measured from all three root canals of the maxillary first molars. This was done to not only determine the amount of expansion achieved during treatment, but to also evaluate the amount of rotation of the maxillary first molars. The intermolar width reported in the results is the center of the palatal root canal of the right maxillary first molar to the center of the palatal root canal of the left maxillary first molar because it has been reported that the molar will rotate around it's palatal root due to it's size. [19] Therefore, the amount of rotation can be lessened as a factor of the amount of expansion.

The level of the pulpal furcation is defined as the furcation entrance. The furcation entrance is the "transitional area between the undivided and the divided part of the root."[1] Using CBCT to study the pulpal furcation, the axial plane is at the level just apical to the pulpal chamber and just coronal to the root furcation. It is the axial plane at the level just when three pulpal chambers can be distinguished from one another. We chose the level of the pulpal furcation due to the importance of having

healthy periodontal architecture in this region. "The furcation area is often inaccessible to adequate instrumentation and frequently the roots present concavities and furrows which make proper cleaning of the area after resective surgery impossible."[20]

On average, patients with rapid maxillary expansion had a significant increase in intermolar width of 3.05 mm ± 2.10 mm ($P<0.001$), between the palatal root canals, and a significant decrease of 0.28 mm ± 0.65 mm ($P<0.001$) in bone thickness on the mesiobuccal surface of the permanent maxillary first molar. The distobuccal and the palatal surface of the maxillary first molars did not show a significant decrease or increase. Two studies by Garib et al[10], in 2006 and Rungcharassaeng et al[9], in 2007 studied the effects of rapid maxillary expansion using three-dimensional images. Garib et al[10], in 2006, reported a significant decrease in bone thickness of the maxillary first molars on the mesiobuccal surface, -0.7 mm. These findings were observed after a 3-month retention period following rapid maxillary expansion. Rungcharassaeng et al[9], in 2007, also reported a significant decrease in buccal bone thickness on the maxillary first molar, of 1.24 mm. These findings were taken within three months of retention following rapid maxillary expansion. The histological findings of Starnbach[6] initially showed that after two weeks after expansion, "the alveolar bone surface was irregular and scalloped and showed many areas of bone resorption." Starnbach's[6] study continued with, after three months of expansion, "the dental supporting structures had reacted and were adjusting to the expansion forces." Three months of retention following showed "much evidence of recent alveolar bone

formation was apparent." Three months of retention in addition to three months after removal of retention showed, "continued adjustment toward 'near normal' dental supporting structures." The findings in our study might indicate, "continued adjustment toward 'near normal' dental supporting structures", that Starnbach's[6] studied observed histologically and compared to Garib et al[10] and Rungcharsaeng et al[9], Greenbaum et al[7] measured four periodontal parameters, a mean of 1.8 years out of orthodontic retention, including level of marginal alveolar bone height, attachment levels (from CEJ), probing depths, and width of keratinized gingival. The results demonstrated that there were minimal differences in periodontal condition when compared to the control group.

The control group had, on average, a non significant increase in intermolar width of 0.19 mm ± .90 mm, between the palatal root canals, and a non significant decrease of 0.07 mm ± 0.54 mm in bone thickness on the mesiobuccal surface of the maxillary first molar. The distobuccal and the palatal surface of the maxillary first molars also did not show a significant decrease.

The mesiobuccal bone of the expansion group had a statistically significant difference ($P \leq 0.001$) when compared to the control group. On average, patients without expansion had 0.37 mm thicker bone mesiobuccal to the maxillary first molar mesiobuccal root at the level of the pulpal furcation after orthodontic treatment was completed (Table II). Both, the experimental group and the control group, had the largest intermolar width increase between the mesiobuccal root canal. The rotation of the maxillary first molars along with the rapid maxillary expansion could of

potentially lead the mesiobuccal bone thickness to have the greatest amount of decrease. According to Garib et al[10], the mesiobuccal root is usually more prominent and likely to be more vulnerable to attachment loss than the distobuccal root.

Since our method included measuring between all three canals (mesiobuccal, distobuccal, and palatal) of the maxillary first molars, we were able to detect rotation. On average, the maxillary molars were distally rotated and the mesiobuccal intermolar distance increased the most by an average of 4.00 mm ± 1.30 mm. This would be a contributing factor in the statistically significant decrease in bone on the mesiobuccal surface. Using a Pearson Correlation Coefficient, we determined there is a weak correlation between the change in intermolar width and the change in bone thickness, even considering rotations with patients treated with rapid maxillary expansion. Considering this finding, there appears to be other variables that might contribute to whether or not a person will experience a decrease in bone thickness buccal to the maxillary first molars after orthodontic treatment with rapid maxillary expansion. Individual variables that further studies should address include genetics, BMI, and biological markers.

Recording the effects of rapid maxillary expansion after of a full course of edgewise-orthodontic treatment demonstrates that the periodontal components eventually rebound and do not deteriorate to the extent reported by previous studies[9,10]. Rapid maxillary expansion, according to our study, was not a risk factor for causing harmful effects towards bone surrounding the permanent maxillary first molars. Although statistically significant, the change in bone thickness after

comprehensive orthodontics with rapid maxillary expansion was less than the width of periodontal probe and was not considered clinically significant.

CONCLUSION

There was a statistically significant decrease of bone thickness on the mesiobuccal surface of the maxillary first molars after orthodontic treatment of patients treated with rapid maxillary expansion compared to patients treated without expansion. However, the difference was not considered clinically significant. There was no correlation found between the change in bone thickness and the amount of expansion of the maxillary first molars.

Table I.--Rapid maxillary expansion (experimental) and non-expansion (control) group means, standard deviations, ranges of age, treatment time, RME appliance expansion, activation time, rate of appliance expansion, and retention time.

		Experimental Group		Control Group	
		Mean ± SD	Range	Mean ± SD	Range
Age (y):					
	Overall (n=32 per group):	13.67 ± 1.25	11.51-16.75	13.82 ± 0.67	12.66-14.73
	Male (n=17 per group):	13.61 ± 1.24	11.51-16.12	13.84 ± 0.69	11.51-16.12
	Female (n=15 per group):	13.64 ± 1.31	11.89-16.75	13.64 ± 1.31	11.89-16.75
Treatment time (mth):		25.22 ± 4.41	20.81-29.63	24.62 ± 1.58	21.21-28.31
Race:					
	Caucasoid:	28		27	
	Negroid:	3		4	
	Mongoloid:	1		1	
Haas:		8			
Hyrax:		16			
Bonded:		8			
Appliance expansion (mm):	3.05 ± 2.10	0.40-7.80			
Activation time (wk):	7.71 ± 4.93	2-26			
Rate of appliance expansion:	1.03 ± 0.30	2/week - 2/day			
Retention time (wk):	21.12 ± 6.62	11.86-36			

Table II.--Comparison of initial (Time 1) and final (Time 2) measurements of the RME group and Non-Expansion Group with 2 Tailed Paired T-Test. Intra-examiner reliability (r^2). * $P \leq 0.05$, ** $P \leq 0.001$

	Rapid Maxillary Expansion			Non Expansion Group			Intra-examiner reliability	Differences btw groups: RME minus Non-Exp	
Measurement	Time 1	Time 2	Δ Mean ± SD	Time 1	Time 2	Δ Mean ± SD	(r^2)	Time 1	Time 2
Palatal Root Intermolar Width (mm)	37.10 ± 2.85	40.15 ± 3.75	3.05 ± 2.10**	40.27 ± 2.82	40.46 ± 2.97	0.19 ± 0.90	0.99	-3.16**	-0.3
Mesiobuccal Root Intermolar Width (mm)	45.56 ± 3.13	49.57 ± 3.25	4.00 ± 1.30**	49.19 ± 3.15	49.61 ± 2.83	0.42 ± 1.10*	0.99	-3.63**	-0.05
Distobuccal Root Intermolar Width (mm)	45.30 ± 2.95	48.73 ± 3.44	3.44 ± 1.54**	48.79 ± 3.07	48.76 ± 3.04	-0.03 ± 0.85	0.99	-3.50**	-0.03
Mesiobuccal bone thickness (mm)	1.46 ± 0.48	1.18 ± 0.64	-0.28 ± 0.65**	1.62 ± 0.54	1.55 ± 0.62	-0.07 ± 0.54	0.96	-0.16	-0.37**
Distobuccal bone thickness (mm)	2.03 ± 0.56	2.06 ± 0.72	0.03 ± 0.63	2.20 ± 0.45	2.23 ± 0.54	0.03 ± 0.56	0.93	-0.17	-0.17
Palatal bone thickness (mm)	1.27 ± 0.41	1.17 ± 0.56	-0.10 ± 0.69	1.35 ± 0.54	1.10 ± 0.55	-0.26 ± 0.55*	0.9	-0.09	0.07

Figure 1: In the axial view, set the sagittal plane parallel to ANS and PNS.

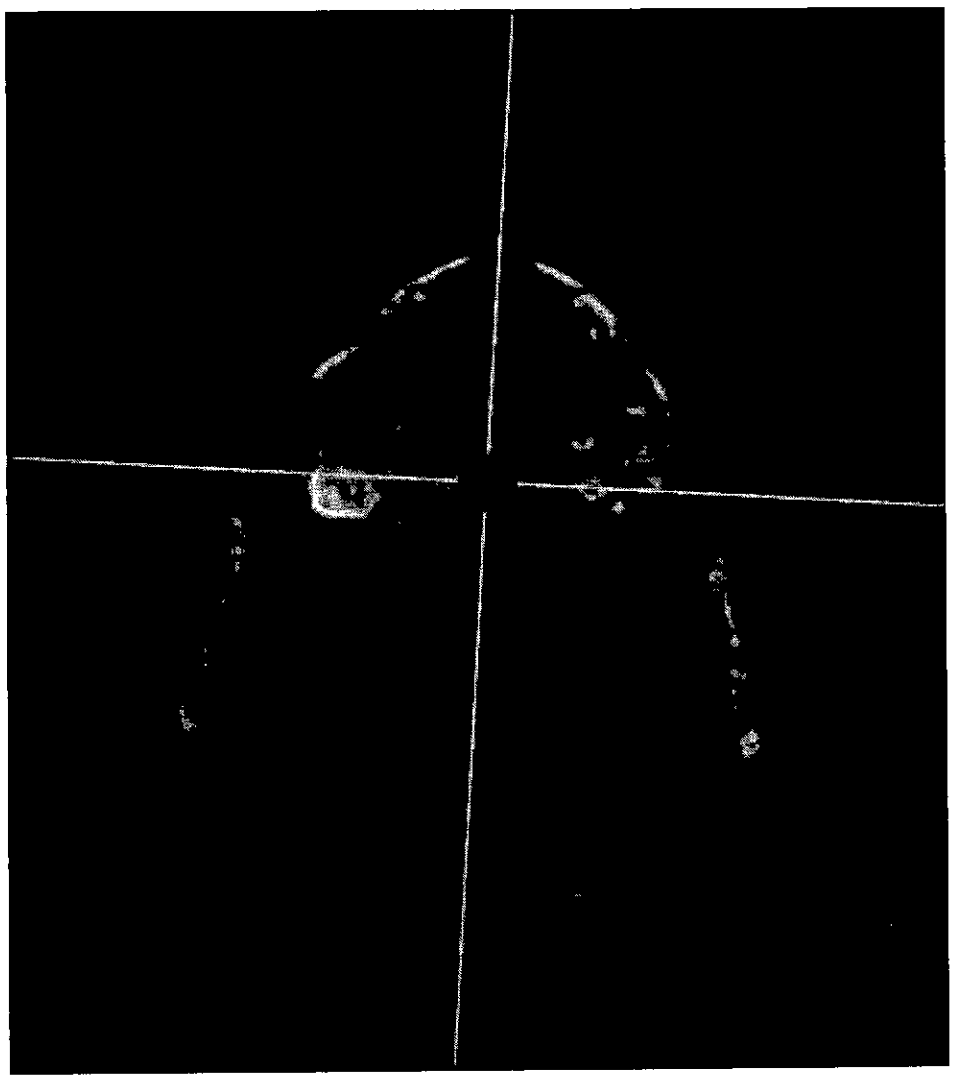


Figure 2: In the sagittal view, set the axial plane parallel to ANS and PNS.

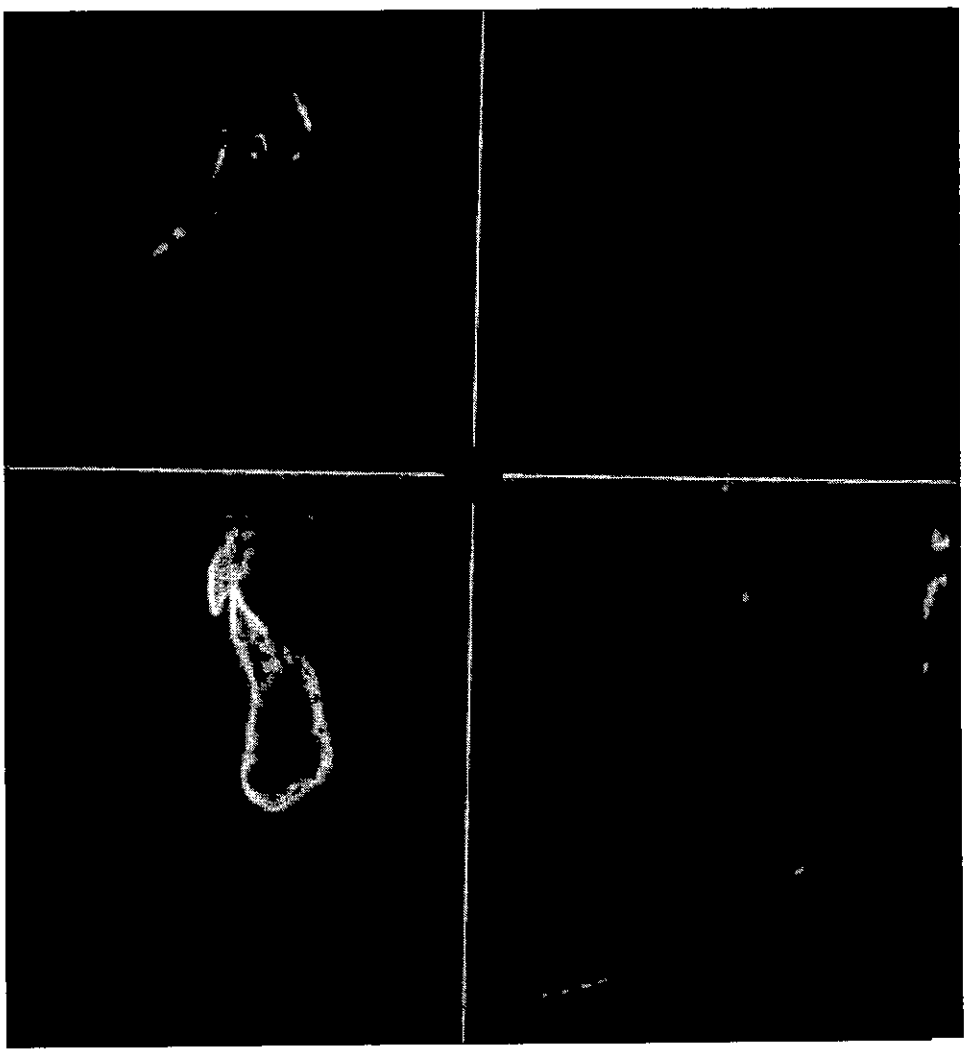


Figure 3: In the coronal view, set the axial plane parallel to the zygomatic arches.

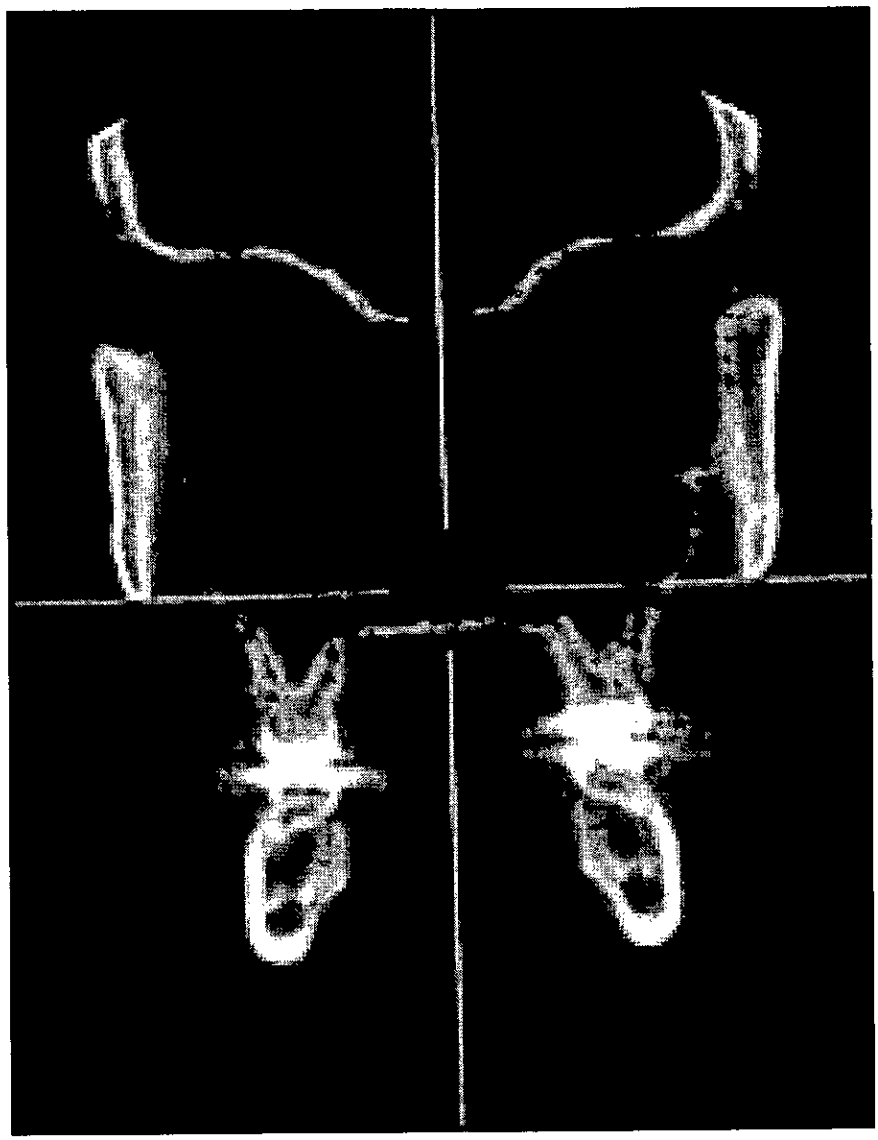


Figure 4a: Coronal to the pulpal furcation of #3

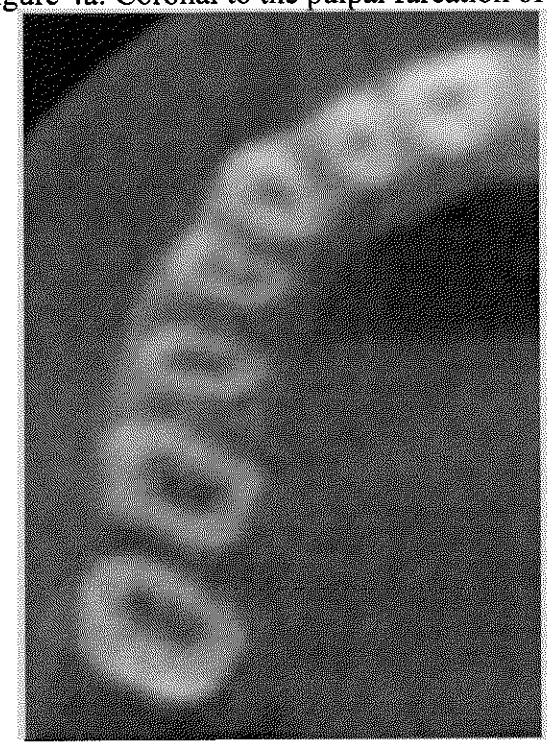


Figure 4b: Apical to the pulpal furcation of #3

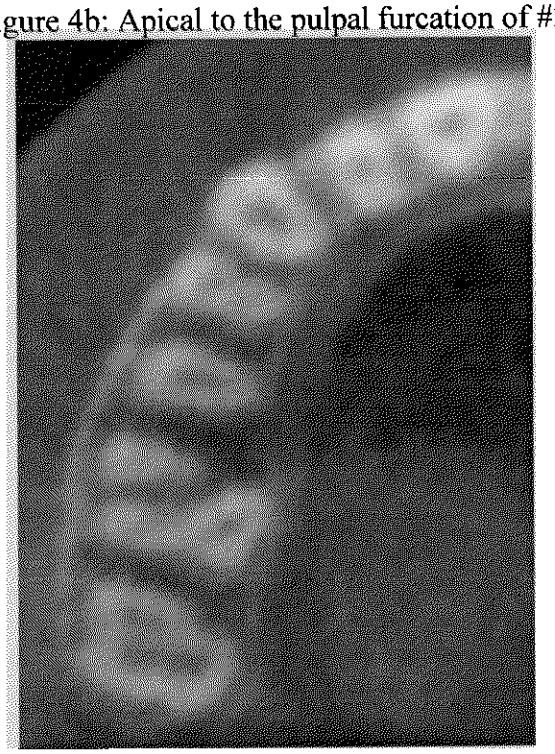


Figure 4c: The pulpal furcation of #3

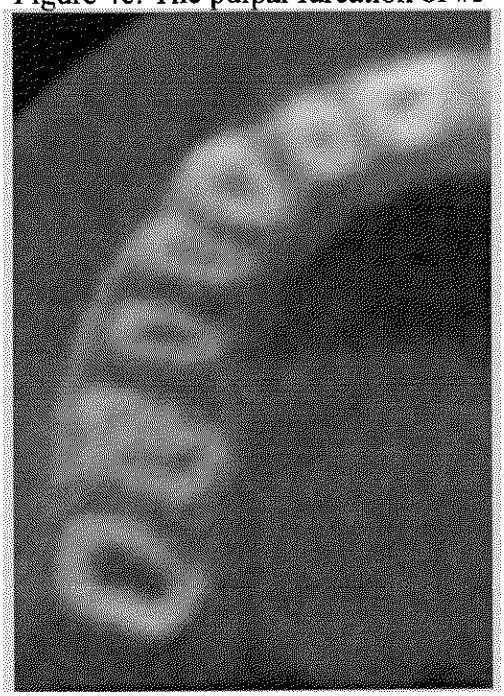


Figure 5a: Set the axial plane at the level of the
maxillary right molar pulpal furcation when making measurements on tooth #3.

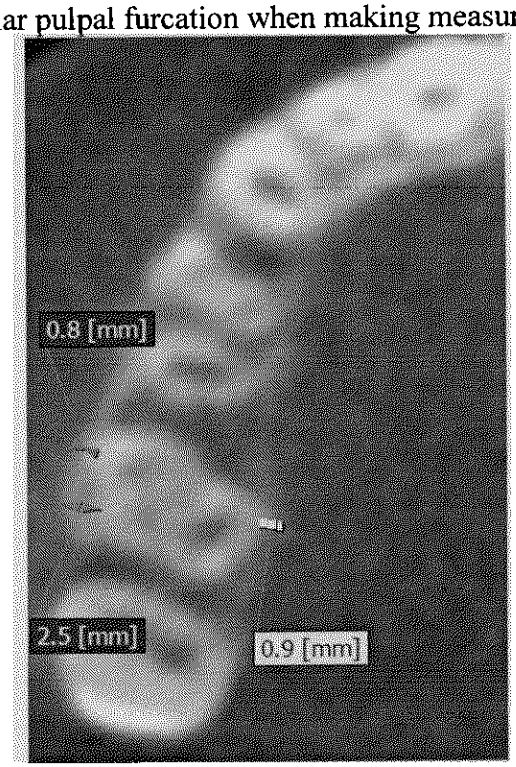


Figure 5b: Set the axial plane at the level of the maxillary left molar pulpal furcation when making measurements on tooth #14.

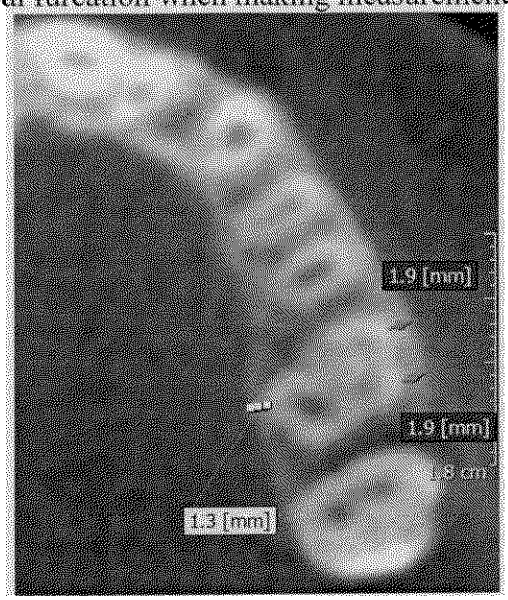
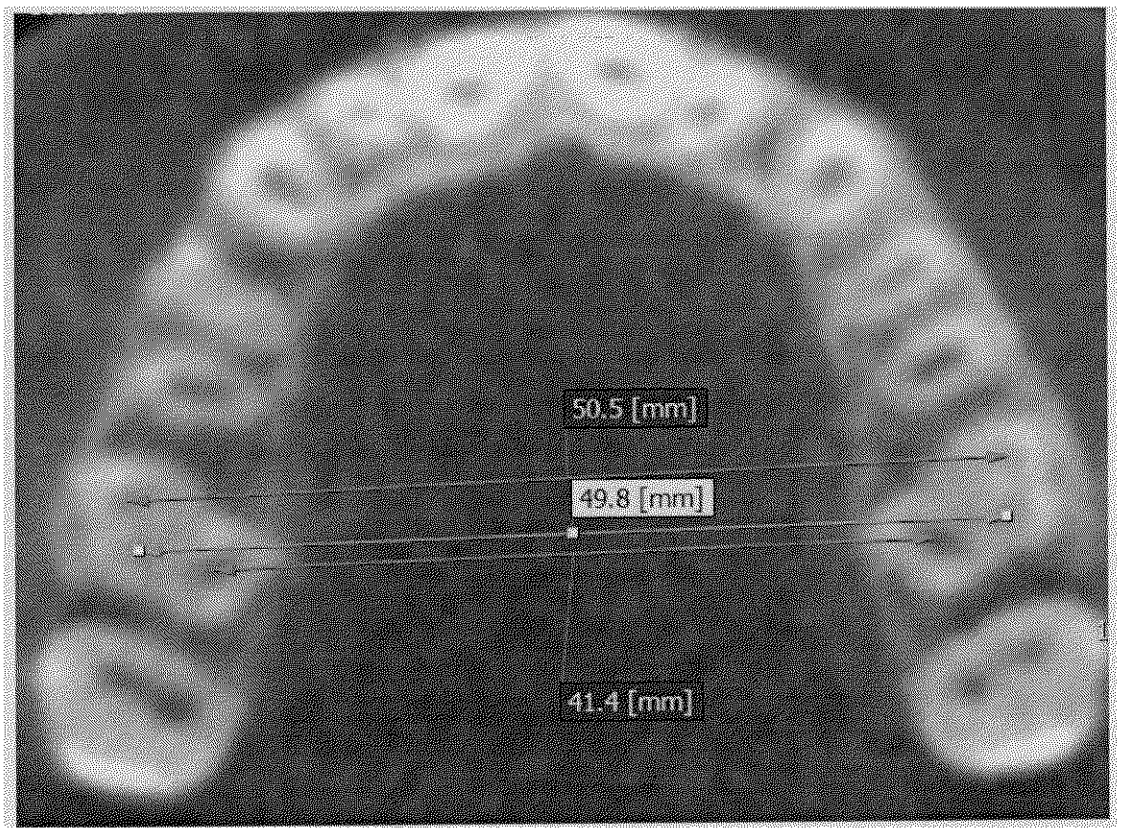


Figure 6: Measure from the center of the right maxillary molar's palatal, mesiobuccal, and distobuccal root's pulp to the left maxillary molar's palatal, mesiobuccal, and distobuccal root's pulp when the axial level is set on both #3 and #14 pulpal furcation.



REFERENCES

1. Lindhe J. Clinical Periodontalogy and Implant Dentistry. 4th ed. Blackwell Munksgaard; 2003. pgs: 744-778.

2. Palomo L, Palomo JM, Bissada NF. Salient Periodontal Issues for the Modern Biologic Orthodontist. Seminars in Orthodontics, Vol 14, No 4 (December), 2008: pp 229-245.

3. Lekhom U, Zarb GA. Ptient selection and preparation. In: Branemark Pi, Zarb GA, Albrektsson T, editors. Tissue-integrated prosthesis: osseointegration in clinical dentistry. Chicago, IL: Quintessence Publishing, 1985, 199-209.

4. Proffit WR, Fields HW. Contemporary Orthodontics. 4th ed. Mosby; 2007. pgs. 4-43, 100, 331.

5. Steiner, G.G., Pearson, J.K. & Ainmao, J. (1981). Changes of the marginal periodontium as a result of labial tooth movement in monkeys. Journal of Periodontology. 52, 314-320.

6. Starnbach H. Facioskeletal and dental changes resulting from rapid maxillary expansion. Angle Orthod. 1966 Apr;36(2):152-64.

7. Greenbaum KR, Zachrisson BU. The effect of palatal expansion therapy on the periodontal supporting tissues. Am J Orthod. 1982 Jan;81 (1):12-21.

8. Timms, Moss. A histological investigation into the effects of rapid maxillary expansion on the teeth and their supporting tissues. Trans Eur Orthod Soc 1971; 263-71.

9. Rungcharssaeng K. Factors affecting buccal bone changes of maxillary posterior teeth after rapid maxillary expansion. Am J Orthod Dentofacial Orthop. 2007 Oct;132(4):428.e1-8.

10. Garib DG. Periodontal effects of rapid maxillary expansion with tooth-tissue-borne and tooth-borne expanders- A computed tomography evaluation. Am J Orthod Dentofacial Orthop. 2006 Jun;129(6):749-58.

11. Leung CC, Palomo L, Griffith R, Hans MG. Accuracy and reliability of cone-beam computed tomography for measuring alveolar bone height and detecting bony dehiscences and fenestrations. Am J Orthod Dentofacial Orthop. 2010 Apr;137(4 Suppl):S109-19.

12. Rupprecht RD. Prevalence of Dehiscences and Fenestations in Modern American Skulls. J Periodontol. 2001 Jun;72(6):722-9.

13. Ballrick JW, Palomo JM, Ruch E, Amberman BD, Hans MG. Image distortion and spatial resolution of a commercially available cone-beam computed tomography machine. Techno Bytes 2008.11.025:573-582.

14. Baumgaertel S, Palomo JM, Palomo L, Hans MG. Reliability and accuracy of cone-beam computed tomography dental measurements. Am. J. Ortho. 2007.09.016: 19-25.

15. Maki K, Inou N, Takanishi A, Miller AJ. Computer-assisted simulations in orthodontic diagnosis and the application of a new cone beam x-ray computed tomography. Orthod Craniofac Res 2003;6(Suppl 1):95-101.

16. Baumrind S, Carlson S, Beers A, Curry S, Norris K, Boyd RL. Using three-dimensional imaging to assess treatment outcomes in orthodontics: a progress report from the University of the Pacific. Orthod Craniofac Res 2003;6(Suppl 1):132-42.

17. Aboudara CA, Hatcher D, Nielson IL, Miller A. A three dimensional evaluation of the upper airway in adolescents. Orthod Craniofac Res 2003;6(Suppl 1):173-5.

18. Garrett BJ. Skeletal effects to the maxilla after rapid maxillary expansion assessed with cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2008 Jul;134(1):8-9.

19. Atkinson, Spencer R.: Orthodontics as a Life Factor. Am. J. Ortho. 25: 1133-1142, 1939.

20. Hamp SENyman S, Lindhe J.,1975, J Clin Periodontol. 1975 Aug;2(3):126-35. Periodontal treatment of multirooted teeth. Results after 5 years.

APPENDIX 1
IRB Approval

Case Western Reserve University
Institutional Review Board

NOTICE OF EXEMPTION (#4)

Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

This protocol is exempt under the #4 category because this involves existing retrospective de-identified data. Prospective data are NOT included in this exemption. De-identified pre-existing data to be collected on 06/25/2009 and after are NOT covered by this exemption.

Responsible Investigator: J. Martin Palomo
Department: Dental Orthodontics
IRB Protocol Number: 20090631
Title: *Case Control Study of Bone Thickness Buccal and Lingual to the Maxillary First Molar Roots Before and After Orthodontic Treatment*
Co-Investigator: Brent Paulus

Exemption Date: June 24, 2009
The Institutional Review Board (IRB) has deemed the above protocol EXEMPT under 45 Code of Federal Regulations (CFR) part 46.101(b)(4). The IRB will not conduct subsequent reviews of this protocol.

Any changes to the protocol that put it under the purview of the IRB would require a formal application to, and approval of, the IRB prior to implementation of the change IRB applications are available at the CWRU IRB Pages, or from the Office of Research Compliance (ORC) at Sears Library Building, #660.

APPENDIX 2

Raw Data for the Non-Expansion group and Rapid Maxillary Expansion group:

ID: Patient's ID number,
Resident: Aus:Austin, Eva:Evangelinakis, Sul:Sullivan, Vel:Velez, Zha: Zhang
Dr: Amb:Amberman, Bee:Beeson, Gri:Griffith, Gus:Gustovich, Fen:Fenell, Pal:Palomo, Raz:Razavi, Sab:Sabat, Sch:Schmahl, Sko:Skorobatckyj, Wen:Wenger.
Initial Crossbite: List of teeth (universal numbering) in lingual crossbite or buccal crossbite (b), 0=No crossbite
R:Race, C: Caucasoid, N: Negroid, M: Mongoloid
M/F: M:male, F:female
Time 1: Initial records
Time 2: Final records
PIW: distance between the centers of the pulpal canals of the palatal roots of maxillary right and left first molars at the level of the pulpal furcation.
MBIW: distance between the centers of the pulpal canals of the mesiobuccal roots of maxillary right and left first molars at the level of the pulpal furcation.
DBIW: distance between the centers of the pulpal canals of the distobuccal roots of maxillary right and left first molars at the level of the pulpal furcation.
3MB: maxillary right first molar buccal bone thickness measured at the level of the pulpal furcation from the height of contour of the mesiobuccal root to the buccal limit of alveolar bone.
3DM: maxillary right first molar buccal bone thickness measured at the level of the pulpal furcation from the height of contour of the distobuccal root to the buccal limit of alveolar bone.
3P: maxillary right first molar buccal bone thickness measured at the level of the pulpal furcation from the height of contour of the palatal root to the buccal limit of alveolar bone.
14MB: maxillary left first molar buccal bone thickness measured at the level of the pulpal furcation from the height of contour of the mesiobuccal root to the buccal limit of alveolar bone.
14DM: maxillary left first molar buccal bone thickness measured at the level of the pulpal furcation from the height of contour of the distobuccal root to the buccal limit of alveolar bone.
14P: maxillary left first molar buccal bone thickness measured at the level of the pulpal furcation from the height of contour of the palatal root to the buccal limit of alveolar bone.

Table 1.--Non-Expansion general information

ID	Resident	Doctor	Initial Crossbite	Final Crossbite	Race	M/F	Start Age (yrs)	Finish Age (yrs)	Tx Time (mos)
BL67	AUS	AMB	4	0	C	F	14.72	16.76	24.39
CI27	AUS	HER	0	0	C	F	14.64	16.59	23.41
HI69	AUS	MEL	0	0	C	M	12.76	14.76	24.07
HO188	AUS	WEN	0	0	C	F	13.52	15.64	25.35
MC147	AUS	FEN	5b,12b	0	C	F	14.73	16.89	25.97
EV17	EVA	GRI	0	0	N	F	12.72	14.65	23.24
KN15	EVA	FEN	0	0	C	M	13.41	15.43	24.16
LI77	EVA	PAL	0	0	C	F	13.80	15.90	25.28
MA329	EVA	WHI	0	0	C	M	14.62	16.56	23.24
MU83	EVA	WEN	0	0	C	M	12.66	14.67	24.20
PE149	EVA	LAW	0	0	M	M	13.30	15.45	25.84
ST214	EVA	AMB	0	0	C	F	13.53	15.45	23.01
AL97	SUL	FEN	0	0	C	F	13.75	15.62	22.39
BO165	SUL	WEN	0	0	C	M	14.28	16.37	25.08
GE41	VEL	LAW	0	0	C	F	14.15	15.91	21.21
LI71	VEL	WHI	0	0	C	F	12.86	15.00	25.71
OS18	VEL	GRI	0	0	C	M	13.73	16.00	27.25
PO112	VEL	WHI	0	0	N	F	14.70	16.62	23.05
RO223	VEL	TRO	0	0	C	M	13.61	15.69	25.05
TH100	VEL	HER	0	0	C	F	13.48	15.51	24.36
BR135	ZHA	DEL	0	0	N	M	14.73	16.69	23.54
DI88	ZHA	SCH	0	0	C	M	13.97	15.89	23.01
JO97	ZHA	AMB	0	0	C	M	12.73	14.80	24.85
LO61	ZHA	RAZ	0	0	C	M	14.73	16.84	25.35
NE74	ZHA	BAU	0	0	N	M	14.47	16.42	23.41
RO228	EVA	FEN	0	0	C	F	13.84	15.84	23.97
JU21	SUL	AMB	5b,13b	0	C	M	14.53	16.88	28.31
HA295	VEL	WHI	0	0	C	F	13.08	15.06	23.74
ZU16	ZHA	WEN	0	0	C	M	13.98	16.12	25.58
MU53	VEL	PAL	0	0	C	M	13.98	16.31	28.04
BA175	EVA	AMB	13	0	C	F	13.34	15.45	25.35
KO82	EVA	Gri	0	0	C	m	13.78	15.97	26.37

Table 2.--Rapid Maxillary Expansion general information

ID	Res	Dr	Time 1 Crossbite	Time 2 Crossbite	R	M/F	Start Age (yrs)	Finish Age (yrs)	Tx Time (mos)	Expander Type	Active Turning (days)	Retention (days)	Turns per day
BE152	POW	Val	3,4	0	M	M	11.75	14.30	30.58	Bonded	182.00	84.00	1
DA134	AUS	Raz	0	0	C	M	16.12	18.75	31.50	Bonded	31.00	98.00	2
GI54	LEU	Pal	0	0	C	F	11.89	14.07	26.20	Bonded	41.00	91.00	1
LA115	LEU	Sko	0	0	C	F	14.95	16.90	23.38	Bonded	19.00	127.00	1
JO199	SHE	Law	5,12	0	C	F	13.74	15.47	20.71	Bonded	30.00	159.00	1
MU22	SHE	Raz	3,4,7,10,13	3	N	M	13.64	15.61	23.61	Bonded	70.00	203.00	1
SH31	SUL	Wen	7,11	0	C	F	12.07	13.77	20.38	Bonded	21.00	245.00	1
CL61	PET	Raz	4,11	0	N	F	16.75	18.62	22.45	Haas	21.00	196.00	1
MA258	ZHA	Law	0	0	C	M	14.03	16.73	32.32	Haas	42.00	119.00	1
GI31	AUS	Raz	7,12,14	0	C	M	11.51	13.96	29.46	Haas	46.00	157.00	1
GO99	SHE	Raz	13	0	C	F	12.55	14.24	20.25	Haas	28.00	133.00	1
LE107	KAC	Bee	13	0	C	M	13.33	15.26	23.24	Hyrax	85.00	147.00	2
SI32	KAC	Raz	0	0	C	F	12.69	14.21	18.18	Hyrax	61.00	83.00	1
WE131	KAC	Wen	10,12,13,14,15	14,15	C	M	12.68	14.89	26.47	Hyrax	70.00	140.00	1
SE61	PAR	Pal	0	0	C	M	14.03	16.36	27.91	Hyrax	56.00	83.00	1
JE10	KAC	Whi	3,4,5	0	N	M	13.33	15.05	20.68	Hyrax	49.00	112.00	1
RU43	LEU	Sch	2,3	0	C	F	14.79	16.92	25.55	Hyrax	28.00	140.00	1
HO164	PAR	Whi	0	0	C	M	13.43	16.16	32.78	Hyrax	28.00	189.00	1
CA57	ZHA	Whi	14	0	C	M	15.28	17.79	30.15	Hyrax	28.00	147.00	1
FR23	SHE	Sko	3,4,12,13,14	0	C	M	14.82	16.71	22.72	Hyrax	63.00	224.00	1
LI76	SUL	Whi	7,10	0	C	M	13.52	15.28	21.21	Hyrax	14.00	140.00	1
FA42	VEL	Law	7,10	0	C	F	14.10	15.90	21.63	Hyrax	31.00	168.00	1
LO75	SHE	Gri	13,14	0	C	F	13.42	15.74	27.75	Hyrax	18.00	252.00	1
SH119	KAR	Sch	0	0	C	M	14.05	17.02	35.67	Bonded	121.00	117.00	1
SC143	SUL	Her	0	0	C	M	14.88	16.72	22.06	Haas	84.00	119.00	1
SF1	SUL	Her	3,4,5,7	0	C	F	14.16	15.94	21.30	Haas	61.00	119.00	1
ST219	AUS	Sko	12	0	C	M	12.77	14.76	23.90	Hyrax	71.00	119.00	1
BE79	VEL	Raz	14	0	C	F	13.04	15.17	25.51	Hyrax	50.00	154.00	1
KO60	VEL	Bee	7,14	0	C	M	12.18	14.28	25.22	Hyrax	98.00	112.00	0.29
DU53	ZHA	Wen	0	0	C	F	12.48	14.78	27.55	Haas	56.00	203.00	1
PE150	ZHA	fen	3,7,10,11,13,14	14	C	F	13.16	15.42	27.16	Hyrax	63.00	210.00	1
MA325	ZHA	Raz	3,4,7	0	C	F	14.81	16.44	19.56	Haas	63.00	140.00	1

Table 3.--Non-Expansion patient's measurements, Time 1 & Time 2

	Time 1									Time 2								
ID	PIW	MBIW	DBIW	3MB	3DB	3P	14MB	14DB	14P	PIW	MBIW	DBIW	3MB	3DB	3P	14MB	14DB	14P
BL67	44.50	50.40	51.50	1.80	1.70	1.80	1.60	1.80	1.70	44.30	52.30	52.40	1.50	1.60	1.80	1.50	2.20	1.40
CI27	39.50	49.50	48.70	2.00	2.80	1.40	1.50	2.40	1.00	39.60	49.80	49.20	1.10	2.10	1.10	2.40	2.70	1.60
HI69	42.50	50.40	51.20	1.80	2.30	1.30	1.70	2.10	2.10	42.50	51.10	51.20	1.80	2.20	1.30	1.80	2.40	0.80
HO188	37.50	45.80	45.70	0.80	1.50	1.00	1.00	2.00	0.80	36.60	45.20	44.40	1.80	2.50	1.20	1.70	2.60	0.80
MC147	41.50	49.40	49.50	1.20	2.30	1.40	1.30	2.00	1.00	40.90	49.30	48.40	2.00	2.60	0.70	1.20	2.60	0.80
EV17	39.20	48.60	48.50	2.10	2.50	1.80	2.80	2.20	2.10	40.70	49.50	49.20	2.40	1.90	2.00	2.60	2.90	3.00
KN15	39.80	49.30	48.80	1.70	2.60	2.30	2.00	2.60	1.80	41.10	50.40	49.90	1.70	2.10	0.70	1.70	2.30	0.50
LI77	41.80	50.70	50.10	1.30	2.00	0.80	1.80	2.10	0.40	41.40	50.50	49.80	0.80	2.50	0.90	1.90	1.90	1.30
MA329	36.90	48.10	46.80	0.70	1.60	1.30	1.40	2.10	1.30	38.00	48.80	47.10	0.60	2.60	0.60	1.40	2.40	0.70
MU83	42.20	52.00	51.40	1.10	2.60	0.90	1.60	2.90	1.30	42.40	52.80	50.50	1.60	3.20	1.30	1.60	3.20	0.70
PE149	40.80	49.70	50.30	1.60	1.80	0.90	1.60	2.10	0.70	42.20	50.40	51.80	1.60	2.40	0.40	1.80	2.50	1.00
ST214	38.20	45.60	46.30	1.70	1.80	1.00	2.50	2.40	1.00	36.00	44.90	45.10	2.00	2.60	1.20	2.10	3.00	0.70
AL97	41.30	49.00	48.50	0.90	0.90	0.70	1.30	1.60	1.10	41.90	49.70	48.10	0.50	1.30	0.70	0.50	0.80	0.30
BO165	40.30	49.60	48.70	1.10	2.40	1.10	1.10	2.10	1.20	41.40	49.60	49.00	1.20	1.60	1.70	1.00	1.70	1.50
GE41	36.40	44.60	45.40	1.20	1.60	0.70	1.40	1.80	0.70	35.30	45.10	44.90	1.20	1.60	0.20	1.10	1.20	0.30
LI71	40.40	47.80	47.50	1.80	1.90	1.10	1.80	1.50	1.30	40.50	48.40	46.70	2.30	3.00	1.60	2.60	2.30	1.20
OS18	36.50	45.70	45.20	1.60	2.30	1.10	1.10	2.50	1.10	36.70	47.60	44.90	0.50	1.50	0.90	0.70	2.20	0.20
PO112	43.20	50.90	52.70	1.90	2.00	1.00	1.80	2.30	0.90	43.50	52.00	52.00	1.80	2.70	0.60	2.20	2.60	1.00
RO223	45.60	55.90	55.50	1.90	2.30	1.70	2.60	2.30	1.40	46.90	55.60	55.10	1.80	2.20	1.00	1.80	1.70	0.90
TH100	38.90	46.90	45.20	1.50	2.10	1.90	1.60	2.70	1.90	39.10	46.30	45.00	1.30	3.20	0.40	1.60	2.40	1.60
BR135	42.90	55.10	54.20	1.80	2.40	2.70	1.70	2.30	3.50	42.70	54.20	54.10	1.90	2.30	2.40	2.60	2.60	2.80
DI88	36.90	49.10	46.80	0.90	2.40	1.30	1.10	1.90	1.60	37.80	49.70	47.00	0.80	1.60	1.20	1.00	1.80	0.80
JO97	37.50	45.40	45.90	1.20	2.10	1.50	1.80	1.80	1.60	38.40	49.20	48.10	0.60	0.80	1.30	0.30	1.90	1.30
LO61	39.80	48.40	47.60	1.50	2.50	1.10	1.90	2.20	1.00	39.20	49.80	48.10	1.50	2.80	1.10	1.40	1.70	1.00
NE74	45.30	56.20	54.30	0.80	2.00	1.60	1.60	2.70	2.00	45.90	55.80	54.60	1.40	2.10	1.90	2.10	2.70	1.40
RO228	44.90	52.50	52.80	1.50	2.00	1.20	1.60	2.20	0.70	43.70	51.10	51.30	1.80	2.40	1.40	2.10	2.00	1.10
JU21	42.60	51.00	50.00	2.30	3.20	1.00	2.30	2.50	0.80	44.10	51.00	50.30	2.00	2.30	0.80	1.60	2.10	0.60
HA295	38.60	47.50	47.60	1.20	1.90	1.60	1.70	2.30	1.80	38.20	47.10	47.40	0.80	1.40	1.50	0.90	2.10	0.80
ZU16	41.10	51.80	49.60	1.90	2.10	1.20	1.50	2.10	1.20	40.50	50.00	49.00	1.60	2.30	1.20	2.50	2.80	1.20
MU53	39.59	48.46	46.91	0.43	1.63	1.18	1.63	2.13	0.62	39.10	48.40	46.00	0.50	1.60	1.20	1.70	2.20	0.70
BA175	34.10	41.70	41.60	2.00	2.50	1.60	2.00	2.50	1.70	34.70	43.60	43.00	1.80	2.50	0.90	0.80	2.30	1.20
KO82	38.20	47.00	46.60	2.40	3.10	2.00	3.80	3.80	2.10	39.30	48.40	46.80	2.20	2.50	1.10	2.90	2.90	0.70

Table 4.--Rapid Maxillary Expansion patient's measurements, Time 1 & Time 2

	Time 1									Time 2								
ID	PIW	MBIW	DBIW	3MB	3DB	3P	14MB	14DB	14P	PIW	MBIW	DBIW	3MB	3DB	3P	14MB	14DB	14P
BE152	35.20	44.00	43.10	0.90	1.90	2.00	1.40	2.50	1.80	42.50	49.50	49.40	0.50	2.40	1.70	1.20	2.40	2.30
DA134	31.00	41.00	40.50	1.40	1.90	1.20	1.60	2.00	1.20	31.80	44.40	42.50	1.40	2.10	0.80	1.90	1.50	1.20
GI54	37.74	47.83	46.17	1.39	1.83	1.18	1.01	2.13	1.45	38.40	49.40	47.80	1.50	2.00	2.10	1.80	2.40	1.60
LA115	35.00	40.73	42.40	1.55	1.02	1.32	1.31	1.18	0.69	36.10	45.00	44.70	0.40	0.80	1.00	1.30	1.70	0.70
JO199	36.33	45.13	43.87	1.83	2.09	1.39	2.05	2.52	1.00	37.00	47.40	45.70	1.60	2.70	1.50	2.10	2.90	1.60
MU22	35.03	44.25	43.23	1.43	2.11	0.97	1.85	1.91	1.37	39.10	50.30	48.30	0.80	2.30	1.30	1.20	2.20	1.20
SH31	35.40	42.00	43.30	2.50	2.50	1.40	2.60	2.40	1.50	37.00	44.80	44.20	0.70	1.10	1.20	0.80	1.50	0.90
CL61	40.90	50.20	51.30	1.10	1.70	0.90	0.80	1.30	1.00	43.20	52.90	53.90	0.30	0.90	0.60	0.60	1.60	0.60
MA258	38.81	47.92	48.12	1.46	1.85	1.17	1.20	1.56	1.63	40.20	51.70	50.80	1.00	3.40	0.70	1.40	1.60	1.20
GI31	34.84	44.38	43.66	1.20	2.15	1.08	1.29	1.88	1.15	41.80	51.00	50.60	0.60	0.80	2.10	0.70	0.70	0.70
GO99	40.00	48.06	46.45	1.44	3.03	1.61	1.39	2.69	1.35	40.90	51.60	49.40	1.20	2.90	1.30	1.10	2.90	1.40
LE107	44.11	55.08	52.72	1.41	1.78	0.99	1.13	2.03	1.13	51.00	59.30	59.00	0.60	1.00	1.50	1.00	0.90	0.70
SI32	36.67	43.21	43.25	1.74	1.63	1.53	1.64	2.03	1.27	37.10	47.00	46.50	1.00	2.00	1.80	1.70	2.40	1.40
WE131	42.38	49.52	49.72	0.95	1.44	2.29	1.09	2.04	1.85	48.20	53.70	53.50	2.50	2.40	0.20	2.10	2.50	0.10
SE61	39.00	48.20	47.60	1.60	2.90	1.20	2.50	2.60	1.40	40.80	51.00	49.60	1.70	3.10	1.00	2.30	3.70	0.70
JE10	33.88	43.53	41.42	1.35	1.80	1.03	1.09	1.95	0.59	37.30	49.10	46.50	0.30	2.00	1.20	1.10	2.40	0.70
RU43	39.82	47.28	46.90	0.74	1.56	1.41	1.19	1.80	1.16	44.00	51.00	51.20	0.00	1.50	1.90	1.30	2.10	1.70
HO164	37.11	46.98	47.13	1.24	2.12	2.50	1.33	1.35	1.98	41.20	52.70	51.10	1.30	2.00	0.60	0.10	1.90	0.20
CA57	35.20	45.60	45.20	1.80	2.00	1.60	1.70	1.90	0.80	37.70	48.90	48.20	0.20	1.80	1.20	1.40	2.30	1.10
FR23	35.90	45.30	45.10	0.70	1.30	1.10	1.10	1.10	1.10	38.80	48.70	47.30	1.70	2.10	1.20	0.90	1.60	0.80
LI76	39.50	47.20	47.60	1.40	2.70	1.40	1.70	2.50	1.80	41.90	51.60	50.30	1.80	2.50	0.70	1.70	2.60	0.40
FA42	40.10	46.90	47.80	2.20	2.60	1.60	2.40	1.80	1.40	41.80	49.70	49.80	2.50	2.50	2.00	2.60	3.10	2.50
LO75	36.28	44.37	43.82	1.97	3.06	1.59	1.50	2.33	1.43	38.70	46.10	46.20	1.40	1.90	1.70	0.50	2.10	1.00
SH119	40.52	49.58	48.49	1.29	2.22	1.24	1.35	1.29	1.38	42.70	53.10	52.50	1.20	2.10	1.60	1.00	1.00	1.20
SC143	38.60	45.60	46.50	0.90	1.40	0.60	0.90	1.40	0.70	43.00	51.20	51.00	2.00	2.40	0.80	1.00	1.80	0.60
SF1	38.40	46.90	47.00	0.90	1.30	0.70	1.10	1.70	1.10	42.90	51.50	50.90	0.60	1.00	0.50	0.70	1.70	0.60
ST219	33.50	41.70	40.80	1.70	2.60	0.80	2.00	2.70	1.30	35.60	43.90	44.00	0.90	2.20	1.60	1.60	2.50	1.60
BE79	37.30	41.90	44.30	1.90	1.90	1.10	1.90	1.90	1.60	39.20	46.50	46.30	0.50	1.70	1.30	1.30	2.60	0.70
KO60	34.80	43.80	42.90	0.70	1.60	1.00	1.30	1.90	1.50	38.80	48.30	47.40	0.40	1.50	1.80	1.40	2.30	0.50
DU53	34.40	41.30	41.80	1.80	2.80	1.30	2.50	3.60	0.60	34.80	45.30	43.30	1.90	3.50	0.90	2.40	3.70	1.60
PE150	35.00	45.20	44.50	0.30	2.80	0.80	1.60	3.30	1.30	42.80	51.50	50.30	0.70	2.30	1.50	0.40	2.30	2.00
MA325	34.60	43.30	42.80	1.20	1.50	1.40	1.90	1.80	0.20	38.70	48.00	47.30	0.70	0.70	1.60	1.10	1.50	0.30

Table 5.--Reliability Raw Data: Time 1 and Time 2 measurements of intermolar width and bone thickness around maxillary first permanent molars.

	Time 1									Time 2								
ID	PIW	MBIW	DBIW	3MB	3DB	3P	14MB	14DB	14P	PIW	MBIW	DBIW	3MB	3DB	3P	14MB	14DB	14P
CI27	39.60	49.90	48.80	2.00	2.90	1.20	1.30	2.30	0.60	39.70	50.10	49.10	1.40	2.50	1.50	2.10	2.40	1.20
MU53	39.11	48.02	47.10	0.32	1.69	1.20	1.72	2.21	0.82	39.30	48.10	45.80	0.30	1.40	1.10	1.40	2.30	0.80
HO188	37.30	46.00	46.10	0.80	1.20	1.00	1.30	1.70	1.30	36.60	44.90	44.70	1.70	2.90	1.30	1.50	2.10	0.90
BL67	45.00	50.80	50.90	1.50	1.30	2.00	1.60	1.80	1.30	44.40	51.70	52.50	1.50	1.70	1.60	1.40	1.80	1.80
MC147	42.10	49.80	48.90	1.50	1.80	1.10	1.50	1.80	0.70	40.60	49.40	48.20	1.80	2.20	0.50	1.60	2.50	1.30
HI69	42.70	50.60	50.60	1.80	2.30	1.10	1.50	1.90	1.80	42.30	51.20	51.20	1.50	2.10	1.10	1.30	1.90	1.40
KN15	40.80	49.20	48.10	2.00	2.20	1.80	2.00	2.10	1.60	41.60	51.10	49.70	1.80	1.80	0.60	1.90	2.20	0.40
LI77	42.00	50.10	50.00	1.40	1.90	0.70	1.60	1.90	0.50	42.20	50.10	49.10	0.40	2.10	0.70	1.90	1.70	0.90
MU83	42.60	51.70	49.80	1.20	2.70	1.00	1.30	2.80	1.20	43.40	52.30	49.70	1.40	2.80	0.90	1.70	2.80	0.50
PE149	40.90	49.50	50.10	1.70	1.60	0.80	1.40	1.30	1.00	42.00	50.20	51.90	1.60	2.60	0.50	1.60	2.30	0.60
MA329	38.40	47.90	46.80	0.60	1.80	1.00	1.50	2.20	1.20	38.40	49.00	46.50	0.30	2.20	0.40	1.20	2.20	0.20
ST214	38.50	45.40	46.30	1.80	1.80	1.30	2.40	2.10	1.10	36.70	44.80	44.70	1.90	2.40	0.90	2.00	2.70	0.50
AL97	41.40	49.00	48.40	0.40	1.10	0.50	1.00	1.50	0.80	41.70	49.50	48.60	0.40	1.20	0.80	0.50	1.20	0.40
EV17	38.90	48.50	48.30	2.20	2.80	1.50	2.90	2.20	2.00	41.30	49.90	48.50	2.00	2.10	1.80	2.30	2.40	2.60
ZU16	41.10	51.90	50.00	1.90	2.00	1.30	1.60	2.40	1.00	40.70	51.00	49.60	1.50	2.30	1.10	2.20	3.30	1.10
DA134	30.90	41.40	40.80	1.40	1.80	1.00	1.80	2.40	1.20	31.30	44.50	42.20	1.30	2.40	0.60	1.80	1.80	0.80
LA115	34.72	40.72	42.04	1.53	1.42	1.20	1.20	1.19	0.62	36.00	44.60	44.70	0.60	1.20	1.10	1.30	2.00	0.90
BE152	35.00	44.40	42.70	1.00	1.70	1.40	1.20	2.20	1.60	42.30	50.40	49.80	0.50	2.20	1.10	1.60	2.40	1.90
GA38	40.40	49.30	48.70	1.80	2.20	1.00	0.90	1.60	0.80	41.60	51.70	50.20	0.70	1.40	1.40	1.00	1.70	0.50
JO199	36.16	45.24	44.44	1.69	1.86	1.00	1.96	2.09	1.17	37.20	46.90	45.30	1.40	2.60	1.30	1.80	2.60	1.70
BI54	34.73	43.52	43.07	0.36	1.80	0.77	0.26	1.34	1.04	33.40	45.60	44.00	0.60	1.80	0.70	0.50	1.80	0.90
MU22	34.99	43.65	43.84	1.41	2.42	1.12	1.99	1.68	1.20	39.50	49.30	47.70	0.80	2.20	0.90	1.40	2.10	1.40
GI54	37.87	47.77	45.91	1.17	2.19	1.11	0.66	2.06	1.10	39.70	48.50	47.20	1.70	2.20	1.80	1.90	2.00	1.20
GI31	34.94	44.47	43.21	1.32	2.31	1.40	1.17	1.50	1.31	41.30	50.40	50.10	0.30	0.60	1.80	0.80	1.20	0.60
SH31	35.80	42.00	43.00	2.30	2.70	0.90	2.50	2.60	0.90	36.90	45.00	43.50	0.40	1.10	1.40	0.70	1.30	1.00
CL61	40.80	49.80	50.70	1.00	1.40	0.90	0.70	1.00	0.80	43.10	52.70	53.20	0.40	0.60	0.70	0.40	1.20	0.80
MA258	39.05	47.58	47.49	1.18	1.70	1.09	1.21	1.82	1.37	41.30	51.60	49.80	1.30	3.10	1.20	1.20	1.60	1.30
GO99	39.94	48.24	46.37	1.65	2.90	1.19	1.42	2.66	1.37	41.60	51.10	49.10	1.00	2.50	0.90	1.20	2.90	1.10
LE107	44.49	54.98	52.48	1.56	1.56	0.99	1.40	1.90	1.40	50.50	59.10	59.00	1.00	1.50	1.30	1.00	0.60	1.10
HO164	36.36	47.43	47.35	1.25	1.95	2.20	1.25	1.49	1.50	41.30	52.00	50.80	1.20	1.60	0.80	0.10	1.60	0.30

TABLE 6.--Paired t-test for initial (Time 1) and final (Time 2) comparing the left and right measurements of bone thickness around the permanent maxillary first molars

Non-Expansion			Rapid Maxillary Expansion		
Paired T-Test Tooth #3 & Tooth #14 (Time 1)					
MB	DB	P	MB	DB	P
0.08	0.08	0.56	0.06	0.96	0.40
Paired T-Test Tooth #3 & Tooth #14 (Time 2)					
MB	DB	P	MB	DB	P
0.06	0.21	0.60	0.07	0.18	0.07

APPENDIX 4

Table 7.--All descriptive statistics: mean, standard deviation, AND range. Comparison of intial (Time 1) and final (Time 2) measurements of the RME group and Non-Expansion Group with 2 Tailed Paired T-Test. Intra-examiner reliability (r^2). * P ≤0.05, ** P ≤0.001

	Rapid Maxillary Expansion (N=32)						No Expansion (N=32)						Intra-examiner reliability (r^2)
	Time 1		Time 2		Change		Time 1		Time 2		Change		
(mm)	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
Palatal Root Intermolar Width (mm)	37.10 ± 2.85	31 - 44.11	40.15 ± 3.75	31.80 - 51.00	3.05 ± 2.10**	0.40 - 7.80	40.27 ± 2.82	34.10 - 45.60	40.46 ± 2.97	34.70 - 46.90	0.19 ± 0.90	-2.2 - 1.6	0.99
Mesiobuccal Root Intermolar Width (mm)	45.56 ± 3.13	40.73 - 55.08	49.57 ± 3.25	43.90 - 59.30	4.00 ± 1.30**	1.57 - 6.62	49.19 ± 3.15	41.70 - 56.20	49.61 ± 2.83	43.60 - 55.80	0.42 ± 1.10*	-1.8 - 3.8	0.99
Distobuccal Root Intermolar Width (mm)	45.30 ± 2.95	40.50 - 52.72	48.73 ± 3.44	42.50 - 59.00	3.44 ± 1.54**	0.90 - 6.94	48.79 ± 3.07	41.60 - 55.50	48.76 ± 3.04	43.00 - 55.10	-0.03 ± 0.85	-1.5 - 2.2	0.99
Mesiobuccal bone thickness (mm)	1.46 ± 0.48	0.30 - 2.60	1.18 ± 0.64	0.00 - 2.60	-0.28 ± 0.65**	-1.8 - 1.55	1.62 ± 0.54	0.43 - 3.80	1.55 ± 0.62	0.30 - 2.90	-0.07 ± 0.54	-1.5 - 1	0.96
Distobuccal bone thickness (mm)	2.03 ± 0.56	1.02 - 3.60	2.06 ± 0.72	0.70 - 3.70	0.03 ± 0.63	-1.4 - 1.55	2.20 ± 0.45	0.90 - 3.80	2.23 ± 0.54	0.80 - 3.20	0.03 ± 0.56	-1.3 - 1.1	0.93
Palatal bone thickness (mm)	1.27 ± 0.41	0.20 - 2.50	1.17 ± 0.56	0.10 - 2.50	-0.10 ± 0.69	-2.09 - 1.1	1.35 ± 0.54	0.40 - 3.50	1.10 ± 0.55	0.20 - 3.00	-0.26 ± 0.55	-1.6 - 0.9	0.9

APPENDIX 5

Table 8.--Correlation between multiple sets of variables

Correlation	Non Exp	RME
Change in Palatal Root Intermolar Width vs Change in Mesiobuccal Bone Thickness	-0.27	0.02
Change in Palatal Root Intermolar Width vs Change in Distobuccal Bone Thickness	-0.35	-0.31
Change in Palatal Root Intermolar Width vs Change in Palatal Bone Thickness	-0.21	-0.06
Change in Mesiobuccal Root Intermolar Width vs Change in Mesiobuccal Bone Thickness	-0.56	-0.03
Change in Mesiobuccal Root Intermolar Width vs Change in Distobuccal Bone Thickness	-0.43	-0.07
Change in Mesiobuccal Root Intermolar Width vs Change in Palatal Bone Thickness	-0.12	-0.07
Change in Distobuccal Root Intermolar Width vs Change in Mesiobuccal Bone Thickness	-0.52	-0.02
Change in Distobuccal Root Intermolar Width vs Change in Distobuccal Bone Thickness	-0.52	-0.25
Change in Distobuccal Root Intermolar Width vs Change in Palatal Bone Thickness	-0.09	0.12
Treatment Time vs Change in Mesiobuccal Bone Thickness	-0.10	0.05
Treatment Time vs Change in Distobuccal Bone Thickness	-0.11	0.00
Treatment Time vs Change in Palatal Bone Thickness	0.04	-0.17
Age vs Change in Mesiobuccal Bone Thickness	0.12	0.06
Age vs Change in Distobuccal Bone Thickness	-0.05	0.16
Age vs Change in Palatal Bone Thickness	0.03	-0.04
Initial Crossbite vs Expansion at Mesiobuccal Canal	0.02	0.03
Initial Crossbite vs Expansion at Distobuccal Canal	0.01	0.36
Initial Crossbite vs Expansion at Palatal Canal	0.02	0.57
Initial Crossbite vs Change in Mesiobuccal Bone Thickness	-0.05	0.05
Initial Crossbite vs Change in Distobuccal Bone Thickness	-0.01	-0.16
Initial Crossbite vs Change in Palatal Bone Thickness	-0.06	0.02

APPENDIX 6

Table 9.-- Comparison between haas type expanders (bonded or haas), (n = 16 pts), and hyrax type expanders (2 banded or 4 banded), (n = 16 pts), for initial (Time 1)and final (Time 2) measurements with 2 Tailed Un-Paired T-Test. Bonded (mm) - Hyrax (mm). * ≤0.05, P ** P ≤0.001

	Differences btw groups: Bonded minus Hyrax	
	Time 1	Time 2
Palatal Root Intermolar Width (mm)	0.86	1.55
Mesiobuccal Root Intermolar Width (mm)	0.85	0.74
Distobuccal Root Intermolar Width (mm)	0.75	0.93
Mesiobuccal bone thickness (mm)	0.01	0.07
Distobuccal bone thickness (mm)	0.12	0.24
Palatal bone thickness (mm)	0.19	0.00

TABLE 10.--Comparison between patients with a posterior crossbite (n = 23 pts) and patients with a anterior crossbite or patients without any crossbite (n = 41 pts) for initial (Time 1) and final (Time 2) measurements with 2 Tailed Un-Paired T-Test. Xbite (mm) - No Xbite (mm). * ≤0.05, P ** P ≤0.001

	Differences btw groups: Post Xbite minus Ant/No Xbite	
	Time 1	Time 2
Palatal Root Intermolar Width (mm)	-1.60*	1.03
Mesiobuccal Root Intermolar Width (mm)	-1.88*	0.33
Distobuccal Root Intermolar Width (mm)	-2.08*	0.56
Mesiobuccal bone thickness (mm)	-0.19	-0.45*
Distobuccal bone thickness (mm)	-0.07	-0.23
Palatal bone thickness (mm)	-0.09	0.05

Table 11.--Comparison between RME (n = 32 pts) and non expansion group (n = 32 pts) for initial (Time 1) and final (Time 2) measurements with 2 Tailed Un-Paired T-Test. RME (mm) - Non-Expansion (mm). ** P ≤0.001

	Differences btw groups: RME minus NonExp	
	Time 1	Time 2
Palatal Root Intermolar Width (mm)	-3.16**	-0.30
Mesiobuccal Root Intermolar Width (mm)	-3.63**	-.05
Distobuccal Root Intermolar Width (mm)	-3.50**	-0.03
Mesiobuccal bone thickness (mm)	-0.16	-0.37**
Distobuccal bone thickness (mm)	-0.17	-0.17
Palatal bone thickness (mm)	-0.09	0.07

Table 12.--Comparison between males (n = 32 pts) and females (n = 30 pts) for initial (Time 1)and final (Time 2) measurements with 2 Tailed Un-Paired T-Test. Males (mm) - Females (mm). * ≤0.05, P ** P ≤0.001

	Differences btw groups: Males minus Females	
	Time 1	Time 2
Palatal Root Intermolar Width (mm)	0.16	1.26*
Mesiobuccal Root Intermolar Width (mm)	1.63*	2.21**
Distobuccal Root Intermolar Width (mm)	0.88	1.76*
Mesiobuccal bone thickness (mm)	-0.11	-0.03
Distobuccal bone thickness (mm)	0.06	-0.02
Palatal bone thickness (mm)	0.16	-0.15

Table 13.--Comparison between patients with a crossbite (anterior or posterior) (n = 26 pts) and patients without a crossbite (n = 38 pts) for initial (Time 1) and final (Time 2) measurements with 2 Tailed Un-Paired T-Test.
Xbite (mm) - No Xbite (mm). * ≤0.05, P ** P ≤0.001

	Differences btw groups: Xbite minus No Xbite	
	Time 1	Time 2
Palatal Root Intermolar Width (mm)	-1.60	0.97
Mesiobuccal Root Intermolar Width (mm)	-2.18*	0.14
Distobuccal Root Intermolar Width (mm)	-2.14*	0.41
Mesiobuccal bone thickness (mm)	-0.06	-0.37**
Distobuccal bone thickness (mm)	-0.01	-0.21
Palatal bone thickness (mm)	-0.05	0.08

Table 14.--Correlation between change in intermolar width and change in bone thickness.

Correlation	RME
Change in Palatal Intermolar Width vs Change in Mesiobuccal Bone Thickness	0.02
Change in Palatal Intermolar Width vs Change in Distobuccal Bone Thickness	-0.31
Change in Palatal Intermolar Width vs Change in Palatal Bone Thickness	-0.06
Change in Mesiobuccal Intermolar Width vs Change in Mesiobuccal Bone Thickness	-0.03
Change in Mesiobuccal Intermolar Width vs Change in Distobuccal Bone Thickness	-0.07
Change in Mesiobuccal Intermolar Width vs Change in Palatal Bone Thickness	-0.07
Change in Distobuccal Intermolar Width vs Change in Mesiobuccal Bone Thickness	-0.02
Change in Distobuccal Intermolar Width vs Change in Distobuccal Bone Thickness	-0.25
Change in Distobuccal Intermolar Width vs Change in Palatal Bone Thickness	0.12

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