Changes in the Volume of bone in the Maxilla after Comprehensive Orthodontic Treatment with and without Rapid Maxillary Expansion

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DEDICATION

This thesis is dedicated to my family. I am sincerely grateful for your unconditional love and unending support.

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Changes in the Volume of bone in the Maxilla after Comprehensive Orthodontic Treatment with and without Rapid Maxillary Expansion

ABTRACT

By

Aparna Chitharanjan

Objectives: To detect changes in the maxillary volume in patients treated with and without rapid maxillary expansion (RME)

Methods: The RME group consisted of 44 subjects, 25 males and 19 females, with a mean age of 13.4 ± 1.2 years. The non-expansion group was matched with the expansion group by age and sex. The maxilla was divided into anterior and posterior regions to detect the region of greater increase in volume of bone. Association between volume changes and intercanine and intermolar widths were also investigated. Results: Subjects with RME had a significant increase in the volume (9.6 ± 4.9cc) when compared to the non-expansion group (6.8 ± 0.2cc) ($P < 0.005$). There was a significant difference in the change

in the anterior maxilla (4.0 ± 2.6cc) when compared to the non-expansion group (1.6 ± 0.7cc) ($P<0.0085$). The intercanine and intermolar widths were smaller among the cases at the beginning of treatment, but had no significant difference when compared to the controls at the end of treatment. Conclusions: There is a significant increase in the volume of the maxilla in cases treated with RME with a greater increase in the anterior region when compared to the controls treated without RME.

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LITERATURE REVIEW

The maxilla is formed by the contributions of the maxillary process, the palatal shelves given off by the maxillary process and the fronto-nasal process. Bhalajhi et al, 2006)[1]. The fronto-nasal process gives rise to the pre-maxillary region while the palatal shelves of the maxillary process forms the rest of the palate. By the 8th week of intra-uterine life the two palatine shelves are in close approximation with each other. The complete fusion of the palate does not occur until post pubertal growth is complete. The connective tissue of the two palatal shelves grow towards each other and finally ossify resulting in their fusion. The dental arch increases in width by sutural growth at the midpalatal suture. Increase in width also results from the growth of the alveolus in a downward but diverging manner. The buccal teeth erupt in a divergent manner and "drift" laterally by apposition of bone on the buccal surface of the alveolus and resorption on the palatal surface. Adjustments occur in the surrounding facial

sutures, including the midpalatal suture, resulting in a rotation of the halves of the hard palate so that the alveoli move buccally. The arch does not alter in width, without some or all the aforementioned changes taking place. Lateral alterations change the anterior, posterior movements of teeth and the alveolus.

The maxilla is formed through intramembranous ossification and is composed of trabecular bone surrounded by cortical bone (Lekhom et al, 1985)[2]. The width of the maxilla has mainly been concerned with the extent to which the sutural growth in the palatal suture contributes to the growth in the width and the contribution of the appositional remodeling of the outer aspect of the maxilla. Scott (1956)[3] described the median suture as the site of active growth during fetal life, but was uncertain whether growth occurred in this suture after birth. Enlow and Bang (1965)[4] considered that the widening of the hard palate and the dental arch were mainly the result of remodeling process. More recent histological studies by Persson 1979[5] and Melsen (1975)[6] have confirmed that growth in the median suture takes place upto adolescence. With the use of implants Krebs

and Skieller (1964)[7] confirmed that growth in the median suture continues until post puberty. Helm et all (1971) concluded that the cumulative growth in the median suture (measured between lateral implants from year to year) followed the same curve in the growth in body height, but the sutural growth terminated earlier than the growth in body height.

In 1957 Bjork and Skieller[8] described the growth of the maxilla in all three planes through metallic implants and was beneficial to determine if the growth activity is the same throughout the length of the suture and to make 3-D estimate of the influence exerted by the growth of the maxilla in all three planes of space. Lateral implants were placed in the zygomatic process of the maxilla, two on each side and the distance increase was measured. He concluded that the maximum increase in width in the median suture was at the level of the first molars.

In another study Bjork and Skieller et al in 1976, lateral implants were placed in the maxilla and used as reference points during growth and maturation. Vectors of growth were determined and sutural growth was calculated.

Authors reported that the development of maxillary height was 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.

A question of clinical interest that has not been clarified is the extent to which the increase in the width of the maxilla is related to the development in the maxillary arch. Increase in the distance between implants placed in the zygomatic process of the maxilla was compared to the dental arch on casts as the minimum distance on the gingival level between the first molars. Nine subjects showed sutural growth between implants were greater than the increase in width of the dental arch at the first molar.

In Cleall et al's[9] used bone marking agents injected intraperitoneally into two groups of 20 Long Evans rats. A series of coronal sections (100 micrometers) were cut off from one group with the base plane touching the tip of the upper incisor and the

tympanic bulla. Sections in the first molar region were analyzed by measuring the increments of bone growth between successive bone markers directly from a calibrated microscope eyepiece. Very little differential growth was noted in the midpalatal suture, suggesting that this suture was growing fairly uniformly from top to bottom, and thereby, largely discounting the suggestion that increase in arch width is due to rotation of the maxillary halves during growth.

Cleall et al., 1965,[10] studied the sutures affected during rapid maxillary expansion on 6 female Macacus rhesus monkeys, ranging in age from thirty to forty months equivalent to a 7-9yr old human. Maxillary and mandibular models and frontal cephalometric head plates were used to determine the degree of orthodontic expansion of the dental arches and to measure the effect the rapid maxillary expansion had on surrounding boney structures, the alveolar arch, and the angular changes in the inclination of the palatal shelves respectively. Four monkeys were treated with rapid maxillary expansion, while the other two were controls. Radiographs were then

taken of the dissected maxillary complex to evaluate the bony relationships.

The maxilla was cut transversly into blocks of 2.5 mm wide and histologically analyzed. When comparing the two controls, both showed similar sutural and bony morphology with normal osteoblastic and osteoclastic activities. The first monkey, sacrificed after a 2 week period, showed the midpalatal suture to be "dislocated leaving a bony defect filled with disorganized fibrous connective tissue and irregularly-positioned spicules of bone". 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 and the midpalatal suture filled by fibrous connective tissue. Mineralized spicules were now projecting into the defect. 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. An occlusal film revealed normal inclination of the maxillary teeth. The morphology of the midpalatal suture closely resembled the control's midpalatal sutures as the suture was now appearing to heal and remodel with both osteoblastic and osteoclastic activity, but the adjacent bone and boney trabeculae were very cellular. 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 and the occlusal films showed well organized and histological normal sutures. The degree of mineralization of the midpalatal suture appeared indistinguishable from the two controls. While the rhesus monkey provides a close approximation to human morphology, differences still exist. An example of

such differences is the rhesus monkey has distinct and separate premaxilla, which articulates with maxillary bones unlike humans with no distinct premaxilla.

To accurately examine the forces produced by rapid expansion techniques, Isaacson et al., 1964,[11] 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 deformation was then recorded and compared with deformations produced by known loads thereby determining the magnitude of the appliance using a force-measuring dynomometer. The study was conducted on five patients ranging from 8.6 years to 15.6 years with four female subjects and one male subject having bilateral crossbites and some degree of maxillary constriction. The expansion screw was opened 0.2mm per activation producing about 3 to 10 pounds of force. A

smaller load was recorded per activation for younger patients compared to older patients revealing increase in resistance with maturity and age. Whether or not the midpalatal suture was open at the time of expansion did not significantly change the forces required to expand at the level of the molars. This study concluded that the major resistance to rapid maxillary expansion is not in the midpalalal suture but the remainder of the maxillary articulations.

Starnbach et al, in 1966,[12] studied maxillary expansion in five Macaca rhesus monkeys equivalent to humans aged 7-9 years. 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 anchored with 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, and an additional 3 months post retention. The maxillae were sectioned transversly into blocks, approximately two and one-half mm thick. The anterior half of the midpalatal suture opened more than posterior at a ratio of 3:2, sometimes as great as 2:1. This study also gives a description of the changes that occur in the midpalatal sutures as a result of expansion.

A review article by Haas et al (1980)[13] deals with the importance of rapid maxillary expansion. Haas states, "in dentofacial 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."

In 2007,Da Silva Filho et al,[14] surveyed 2,016 children, aged 3 to 6 years, of whom 20.8% presented with some form of maxillary constriction. Normal occlusion was observed in 26.7% of the sample. Da Silva Filho, defined 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." The author also described posterior crossbites to be "characterized by a reverse transverse inter arch relationship in response to a reduction in the transverse dimension of the maxillary arch."

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)[15]. 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. 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 et al., 1982)[16]. 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. Conventional histologic and microradiographic means on autopsy material from thirty-three boys and twenty-seven girls aged 0 to 18 years were used for the study. He reported 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.

The etiology of maxillary constriction include environmental factors (mouth breathing attributed to nasal blockage, extra oral habits), genetic factors (cleft lip and palate) or a combination of both (Proffit WR et al., 2007; Al-Battikki et al., 2001)[17]. Harvold et al., 1972,[18] conducted a study to create narrow maxillary arches in Rhesus monkeys by converting them from nasal to obligatory oral respiration.

Da Silva et at did another study to evaluate the efficacy of rapid maxillary expansion for 32 children between 5 and 11 years of age, by inspection of anterio-posterior radiographs. The results confirm that there is a triangular opening in the frontal alveolar area which is greater than in other parts of the midpalatal suture and that there is evidence that with expansion there is a real orthodontic effect of tipping of the posterior teeth even at an early age.

Provatidis C et al[19] presented a paper on the biomechanical effects on the craniofacial complex during rapid maxillary expansions (RME), by using an in vitro experiment compared with a three-dimensional (3D) finite element model of a human skull. For this purpose, a dry human skull with artificially constructed teeth was used. In addition, a 3D finite element model including the craniofacial sutures was developed based on computed tomography (CT) scans. Initially, two types of models were analyzed. In the first model, the total activation of the jackscrew device was applied in one step. In the second model, more steps were applied, taking into account the phenomenon of stress relaxation during RME

treatment. Afterwards, a parametric analysis of the finite element method model was performed using three more models in order to evaluate the influence of craniofacial sutures. Results showed that the maxillae open in a pyramidal shape and that the degree of sutures ossification influences the displacement distribution on the craniofacial complex much more than the phenomenon of stress relaxation. The areas of the maximum stresses and displacements were also determined to be more anteriorly and inferiorly and tapers posteriorly and superiorly to form a pyramidal shape.

With the advent of Cone Beam Computer Tomography (CBCT) in Orthodontics there has been a paradigm shift in imaging and research. Ballerick el al and Palomo et al[20] evaluated the images produced by a commercially available cone-beam computed tomography (CBCT) machine (i-CAT model 9140-0035-000C, Imaging Sciences International, Hatfield, Pa) for measurement and spatial resolution (ie, the ability to separate 2 objects in close proximity in the image) for all settings and in all dimensions. A custom phantom containing 0.3 mm diameter chromium metal markers approximately 5 mm apart in 3

planes of space was developed for analyzing distortion and measurement accuracy. This phantom was scanned in the CBCT machine by using all 12 commercially available settings. The distance between the markers was measured 3 times on the 3-dimensional images by using a Digital Imaging and Communications in Medicine (DICOM) viewer and was also measured 3 times directly on the phantom with a fine-tipped digital caliper. A line-pair phantom was used to evaluate spatial resolution. Thirty evaluators analyzed images and assigned a resolution from 0.2 to 1.6 mm according to the separation of the line pairs. They concluded that there were no statistically significant differences among the 3-dimensional images for any setting, in any dimension, or in images divided by thirds in terms of measurement accuracy. Comparison of the CBCT measurements to the direct digital caliper measurements showed a statistically significant difference ($P < 0.01$). However, the absolute difference was <0.1 mm and is probably not clinically significant for most applications. The worst spatial resolution found was 0.86 mm; spatial resolution was lower at faster scan times and larger voxel sizes and hence concluded that the CBCT

machine has clinically accurate measurements and acceptable resolution.

Deguchi et al[21] conducted a pilot study with CBCT to determine the volume of the maxilla and mandible in subjects with skeletal Class I, Class II, and Class III malocclusions. Thirty female patients were classified into 3 groups according to their skeletal pattern: skeletal Class I (0 degrees < or =ANB <6 degrees), Class II (ANB > or =6 degrees) and Class III (ANB <0 degrees). The volumes of the maxilla and the mandible were measured with CBCT (CB MercuRay (Hitachi Medico)). The upper reference line was the lower side of the palatal plane (anatomic posterior nasal spine-anterior nasal spine line). The boundaries of alveolar bone and tooth crown were hand-drawn. The volume of the mandible without a tooth crown was the whole bone, including the condyle. The author concluded that there was no trend for Class III subjects to have larger mandibles (P = 0.08) compared with Class II subjects. Subjects with skeletal Class III had a significantly larger ratio (P = 0.005) compared with Class II subjects, but the ratio of the maxilla and mandible volumes in skeletal Class III subjects was

significantly larger (P = 0.005) compared with Class II subjects.

Christie et al[22] examined the maxillary response on the transverse dimensions immediately after rapid palatal expansion (RPE) using CBCT. Twenty four children requiring RPE were examined. The width of the nasal cavity at the level of the maxillary first molar and the first premolar, the width of the basal bone and the width of the mid palatal suture at the level of the first premolar and canine were calculated before treatment and soon after expansion. There was a significant difference in the transverse dimensions at all levels with the greatest increase in the mid palatal suture followed by basal bone and nasal cavity. As a result of RPE, the midpalatal suture opened in a parallel fashion with significant nasal width, width of the basal bone , increases at the levels of the maxillary first molar and second deciduous molar (second premolar if present) , and canine. There were significant midpalatal suture openings at the levels of the first molar, second deciduous molar (second premolar if present), first deciduous molar (first premolar if present), and canine. There was

significant buccal tipping of the first molars with mean increases of 6.2° for the right molar and 5.6° for the left molar.

Franchi et al[23] evaluated the density of the midpalatal suture as assessed by low-dose computed tomography (CT) before rapid maxillary expansion (RME), at the end of active expansion, and after a retention period of 6 months. Seventeen Caucasian subjects with constricted maxillary arches were treated with maxillary expansion using RPE's. Standardized axial CT images parallel to the palatal plane and passing through the trifurcation of the maxillary right first molar was made and their densities were calculated in Hounsfield units. The densities were smaller soon after expansion when compared to before the start of treatment in and no difference in the densities six months after retention when compared to before the start of treatment.

Gohl E et al and Nguyen et al compared changes of skeletal and dental structures of the maxillary palatal vault in a group of growing patients treated for posterior crossbite before and after rapid palatal expansion (RPE) with changes over time in a control group

using CBCT, and concluded that there were no statistically significant differences in palatal volume at baseline or at progress scan between the RPE patients and controls. There were significant differences in percentage and absolute changes in maxillary width measured from molar to molar and canine to canine between RPE group and controls, but no significant differences in maxillary vault height or anterio-posterior dimension changes.

Franchi L et al and Baccetti T et al studied the density of the midpalatal suture as assessed by low-dose computed tomography (CT) before rapid maxillary expansion (RME) (T0), at the end of active expansion (T1), and after a retention period of 6 months (T2). The researchers concluded that the effective opening of the midpalatal suture by RME in prepubertal subjects was associated with a significant decrease in sutural density. The sutural density after 6 months of retention post-RME indicated reorganization of the midpalatal suture, since it showed values similar to the pretreatment ones.

Correction of dental crossbites is recommended in mixed dentition because it "eliminates functional shifts and wear on the erupted permanent teeth, and possibly dento-alveolar asymmetry" (Langberg et al., 2005)[24]. 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)[25]. 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).

Maxillary expansion in growing patients can be achieved dentally by orthodontic expansion, skeletally by orthopedic expansion, or a combination of both. The decision to do one or the other depends on the anatomic basis of the problem. The primary indication for rapid palatal expansion is a true skeletal maxillary deficiency in the transverse plane of space (Proffit et al 2000). Orthopedic expansion with an RME utilizes a fixed

appliance to apply a sufficient force on the palate to result in the separation at the level of the suture. Although ideally orthopedic expansion would only result in the aforementioned skeletal effects; it has been repeatedly established that orthodontic side effects, namely buccal tipping of the posterior teeth, is a consistent finding. In growing patients, the ratio of skeletal expansion to dental expansion ranges from 35%-58% (Will et al 2000, Ladner et al 1995)[26].

Betts in 1995[27] used the Rocky mountain transverse analysis, which attempts to identify the skeletal discrepancy and also quantify the magnitude by developing population norms of the ratio of the mandibular width (measured from the two antigonial notches on either side) to the maxillary width (measured from two jugale points) to help differentiate true skeletal transverse discrepancy to dentoalveolar changes.

This paper is an effort to compare the increase in the volume of bone of the maxilla in adolescent patients treated with and without maxillary expansion using CBCT

and correlating it with the change in the width of the maxilla measured at the level of the molar and canine.

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STATEMENT OF THESIS

The objectives of this research is to 1) investigate changes in the volume of bone in the maxilla in adolescent patients treated with rapid maxillary expansion and adolescent patients treated without expansion following orthodontics, 2) assess differences in the volume of the maxillary bone at the end of orthodontic treatment in patients treated with maxillary expansion and without maxillary expansion, and 3) evaluate volume changes in the anterior and posterior aspect of the maxilla.

Hypothesis

1. **There is no difference in the volume of the maxilla before and after treatment with RPE.**
2. **There is no difference in the change in the volume of the maxilla in patients that have undergone orthodontic treatment with and without RPE.**
3. **There is no difference in the volume of the maxilla in the experimental and control groups at the end of orthodontic treatment.**
4. **There is no difference in the change in the volume of the anterior and posterior maxilla following Orthodontic treatment.**

Changes in the Volume of the Maxilla after comprehensive orthodontic treatment with and without Rapid Maxillary Expansion

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MANUSCRIPT DRAFT

Title: Changes in the Volume of the Maxilla after comprehensive orthodontic treatment with and without Rapid Maxillary Expansion

Article Type: Original article

Keywords: Cone beam computed tomography (CBCT), rapid maxillary expansion, maxillary volume.

ABSTRACT

Objectives: To detect changes in the maxillary volume in patients treated with and without rapid maxillary expansion (RME)
Methods: The RME group consisted of 44 subjects, 25 males and 19 females, with a mean age of 13.4 ± 1.2 years. The non-expansion group was matched with the expansion group by age and sex. The maxilla was divided into anterior and posterior regions to detect the region of greater increase in volume of bone. Association between volume changes and intercanine and intermolar widths were also investigated. Results: Subjects with RME had a significant increase in the volume (9.6 ± 4.9cc) when compared to the non-expansion group (6.8 ± 0.2cc) ($P < 0.005$). There was a significant difference in the change in the anterior maxilla (4.0 ± 2.6cc) when compared to the non-expansion group (1.6 ± 0.7cc) ($P<0.0085$). The intercanine and intermolar widths were smaller among the cases at the beginning of treatment, but had no significant difference when compared to the controls at the end of treatment. Conclusions: There is a significant increase in the volume of the maxilla in cases treated with RME with a greater increase in the anterior region when compared to the controls treated without RME.

INTRODUCTION

The etiology of maxillary constriction includes environmental factors (mouth breathing attributed to nasal blockage and oral habits), genetic factors (cleft lip and palate) or a combination of both[28]. Maxillary expansion in growing patients can be achieved dentally by orthodontic expansion, skeletally by orthopedic expansion, or a combination of both. The decision to do one or the other depends on the anatomic basis of the problem. The primary indication for rapid palatal expansion is a true skeletal maxillary deficiency in the transverse plane of space[29]. In growing patients, the ratio of skeletal expansion to dental expansion ranges from 35-58% [30].

The rocky mountain analysis[31] described landmarks and measurements to assess transverse discrepancies of the maxilla and mandible using frontal cephalograms and the differential was calculated according to population norms relative to age. This analysis helps to identify the magnitude and location (maxilla or mandible) of the discrepancy. Many researchers have conducted two

dimensional studies measuring the amount of maxillary expansion, the site of greatest expansion and have correlated the maxillary changes with the amount of separation seen at the palatal suture after Rapid Maxillary Expansion. [32333435]

Deguchi et al[36] did a pilot study using CBCT images to determine the volumes of the maxilla and mandible in subjects with skeletal Class I, II, and III malocclusion. The study sample included thirty female patients (10 in each group) with no history of orthodontic treatment. The upper reference for the volume of the maxilla was the lower side of the palatal plane and the lower limit was hand drawn to eliminate the crowns of the teeth. The authors results inferred that the ratio of the maxillary and mandibular volumes in skeletal Class III subjects was significantly larger compared to Class II subjects. In this study the sample size was limited to only ten subjects per group and the subjects were only women.

In the 1940's, Charlie Tweed introduced the "Tweed" mechanics that gave emphasis in arch form by maintaining intermolar and intercanine widths and thereby having a high rate of extraction cases. In recent years, however,

expansion non-extraction trends have been growing in popularity where expansion is done to gain arch length and thereby avoid extraction making non-extraction treatment plans the order of the day. More recently, using a computer generated model and program, Noroozi et al. [37] found that each one millimeter of intermolar expansion increases the arch perimeter approximately 0.3 mm. Yet, the question of increasing intermolar width thereby relieving crowding (in most cases in the anterior) still remains unanswered.

With the advent of CBCT, three dimensional measurements can be used to assess and quantify the changes in the maxilla. This study compares the volume change in the maxilla among cases treated with and without expansion and assesses any association of volume change to change in the interrmolar and intercanine widths using CBCT.

MATERIAL AND METHODS

This case control study was approved by the Case Western Reserve University Institutional Review Board (IRB). Data were derived from pretreatment and post-treatment Cone Beam Computed Tomography (CBCT) scans (CB MercuRay™,

Hitachi Medical Systems America Co. - Twinsburg, OH) using the 2mA setting and the largest field of view (0.38 voxel size). A total of 431 pretreatment patient records with CBCT scans, photographs and medical history forms were available. Using an expected effect size of 3cc, a standard deviation of 5.12cc, a two-tailed α of 0.05, and β of 0.10, the estimated sample size was 44 subjects in the experimental group and 44 age and gender matched controls.

Adolescent orthodontic patients between the ages of 11 to 15 at the start of treatment, with no history of previous orthodontic treatment, no deciduous teeth still present, no extracted permanent maxillary teeth and those treatment planned for either a 2 banded hyrax, 4 banded hyrax, Haas expander or a bonded expander were used in this study. Both maxillary first molars should be present and erupted into occlusion determined from CBCT.

The control group was matched by age and sex at the start of treatment having the same criteria except that they were not treatment planned for any expansion therapy.

A single operator (AC) collected all 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) to measure the maxillary volume, the intermolar and intercanine widths and the anterio-posterior dimension of the maxilla. 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,. Microsoft Excel (Version 12.1.9) was used to record and manage the data obtained. Data was first entered into Excel and then exported to Statistical Package for Social Sciences for analysis.

METHOD(Figures 1-9)

Slice thickness will be set default at 0.38 mm as a standard voxel height. The data was obtained using the following steps:

1) Maxillary teeth are carefully sculpted out at the level of the CEJ (Fig 1). 2) In the sagittal view the head is oriented to ANS-PNS and in the coronal view the head is oriented to the key ridges of the zygomatic arch which are the two reference planes in this study to obtain standardization of the isolation of the maxilla. (Fig 2a;2b) 3)Once the head has been oriented, the slice thickness is increased in the sagittal view to include the entire maxilla and a cut is made at the level of the key ridges in the coronal view to obtain a uniform cut through the entire thickness if the maxilla. (Fig 3a;3b). 4) Once the superior border of the maxilla is defined, all remaining structures are sculpted out. (Fig 4a;4b). 5) Seeding points are then placed in all three views and the volume is calculated. 6)The maxilla in this study is divided into anterior and posterior segments by measuring 6mm posterior to the incisive foramen parallel to the midpalatal raphae.(Fig 6). 7) The method used is as follows: The maxilla is once again oriented to ANS-PNS in the sagittal view. In the coronal view a line is drawn 6mm from the incisal foramen posteriorly parallel to the midsagittal plane. 8) The slice thickness is once again

increased in the axial view to cover the entire palate and a cut is made perpendicular to the aforementioned line 6mm posterior of the incisive foramen in the coronal view. 9) The anterior segment is cut and the resultant image is defined as the posterior maxilla.(Fig 7). 10) Seed points are added in all three planes and the volume is measured. Similarly the posterior segment is cut and the anterior volume in calculated (Fig 8). 11) The intercanine width, intermolar width and the distance from ANS to PNS was also measured. The deepest concavity at the CEJ between the two maxillary first molars and canines were measured in the coronal view and the linear measurement between ANS and PNS was measured in the sagittal view. (Fig 9a;9b)

STATISTICAL ANALYSIS

Data was analyzed using Statistical Package for the Social Sciences (SPSS 17.0, Inc. - Chicago, IL). A single operator (AC) collected all measurements. Three weeks after the initial measurements, thirteen subjects from the rapid maxillary expansion group and thirteen subjects from the non-expansion group were randomly selected for

repeat measurements using a random number generator. The intraclass correlation values ranged from .85 to .99 for all measurements taken (Table II).

Descriptive statistics were calculated for all the continuous variables. Paired t-tests were used to analyze the bone volume, intercanine, intermolar widths and anterio-posterior length of subjects before and after orthodontic treatment. Differences between the rapid maxillary expansion (experimental) and non-expansion groups (control) were tested with independent t-tests.

RESULTS

Demographics

The study sample consisted of 88 subjects, 44 cases and 44 controls. Cases included 25 males and 19 females with a mean age of 13.4 ± 1.2 years treated with maxillary expansion followed by comprehensive orthodontics and a control group matched by age and sex treated with comprehensive orthodontics only. The treatment time was 39.7 ± 10.6 months for the expansion

group and 36.05 ± 12.1 for the non-expansion group. A descriptive summary of gender, age at initial and final records, treatment time and expander information is shown in Table I.

There was a higher change in the volume of the maxilla among the cases treated with RME (9.6 ± 4.9cc) when compared to the cases treated without RME (6.8 ± 4.2cc) ($P<0.005$). A significant increase was seen in the anterior maxilla (4.2 ± 0.4cc) in the experimental group compared to the control group (1.6 ± 0.7cc) ($P<0.008$). This difference further validates the two dimensional radiographic studies wherein there is more radiolucency seen in the anterior maxilla immediately after RME (Table II).

There was a significant difference ($p<0.007$) in the volume prior to treatment among the cases (20.8 ± 5cc) when compared to the control group (23.8 ± 5.61cc) but the difference was not statistically significant ($p<0.075$) in the final volume between the cases 30.4 ± 5.2cc and controls 30.72 ± 5.3cc (Table IV)

On average, patients with rapid maxillary expansion had an increase in intermolar width of 3.0mm ± 0.3mm

(P<0.001),when compared to patients treated without RME whose intermolar width only increased by 0.7mm ± 0.3mm. There was no significant difference in their final intermolar width, the patients treated with RME being 34.8 ± 2.3mm and patients treated without RME being 35.0 ± 2.0mm (P<0.68).

When we stratify the sample by gender male patients show a slightly greater net change in the amount of volume of bone (7.02 ± 3.62cc) when compared to the female patients (6.69 ± 4.95cc). But, even in the control group the male patients show a larger increase in volume (7.03 ± 3.63cc) when compared to female patients (6.69 ± 4.95cc) which leads us to believe that the male patients had more growth or were in their growth spurt during orthodontic treatment whereas the female patients did not have as much inherent growth.

There was no significant difference in the anterior-posterior dimensions measured from anterior nasal spine to posterior nasal spine in the case and control group prior to or at the end of orthodontic treatment.

DISCUSSION

The advent of Cone Beam Computed Tomography (CBCT) has proven to be a powerful tool for research, orthodontic diagnosis and outcomes assessment. According to Ballrick et[38] al, CBCT scans have acceptable resolution and can make clinically accurate measurements. In earlier studies with 2-D radiographs the expansion was believed to be pyramidal in form with the base being more anterior and inferior (Bell et al)[39] . The immediate effects of rapid maxillary expansion are studied, but the possible long-term accommodation and bone fill in the radiolucent areas and bony remodeling has not been observed. In our study, initial records before any treatment and final records immediately after comprehensive orthodontic treatment were analyzed.

Our study suggests that expansion therapy in true maxillary transverse deficiency is an extremely valid treatment option to increase maxillary width and bone volume meet the standards or norms. It is clear in this study that there is a significantly larger change in the maxillary volume in cases treated with RME when compared

to cases treated without RME. As the palate expands there is a significant increase in the anterior volume and intercanine width which may suggest that crowding of the anterior teeth due to a constriction of the anterior maxilla may be relieved by RME.

In future studies, it may be beneficial to stratify the appliance used for the expansion and the mechanics used in the comprehensive orthodontic treatment to better understand the various types of expanders and orthodontic treatment mechanics. Also, the retention period immediately after the expansion was completed is not documented and studied as that may influence relapse (if any) of the expansion. It will be of interest to measure the molar and canine angulations to correlate the amount of expansion to dento-alveolar changes.

CONCLUSION

There was a significant increase in the volume of the maxilla in cases treated with RME with a greater increase in the anterior region when compared to the controls treated without RME. There was no significant

difference in the final volume between cases and controls which suggests that RME is a good treatment option for narrow maxillas'. Since there was a greater increase in the volume of the anterior maxilla, it is valid to treat anterior crowding due to a constriction of the anterior maxilla with the absence of a posterior cross bite (constriction). There was no significant difference in the change in the volume of the maxilla between males and females, but the males had a higher volume at the end of treatment suggesting that the males had a larger growth spurt during treatment compared to females. The intercanine and intermolar widths were smaller in the case group before starting treatment, but had no significant difference when compared with the controls at the end of treatment. The anterio-posterior length of the maxilla had no significant difference between the cases and controls before any treatment and at the end of comprehensive orthodontic treatment.

Table I.—Descriptive Statistics of the Study Sample

Rapid maxillary expansion (experimental) and non-expansion (control) group means, standard deviations, ranges of age, treatment time, RME appliance

		N	EXPANSION		NON-EXPANSION	
VARIABLES			Mean±SD	Range	Mean±SD	Range
AGE(yrs)	Overall (T1)	44	13.31 ± 1.22	11.1-15.5	13.58 ± 1.14	11.2-15.6
	Overall (T2)		16.11 ± 3.27	13.3-17.8	16.56 ± 3.32	13.3-17.3
	Males(T1)	25	13.43 ± 1.24	11.8-15.6	13.62 ± 1.04	11.3-15.5
	Males(T2)		16.13 ± 2.30	15.2-17.4	16.55 ± 2.27	13.5-17.2
	Females (T1)	19	13.41 ± 1.24	11.1-15.6	13.62 ± 1.04	11.4-15.5
	Females (T2)		16.21 ± 2.27	15.3-16.9	16.70 ± 3.03	13.3-17.3
TX TIME (mnths)	Overall	44	32.5 ± 3.2	28.4-40.2	29.9 ± 2.34	24.34 - 36.32
	Males	25	31.0 ± 3.0	28.4-40.6	27.89 ± 2.46	24.34 - 35.78
	Females	19	32.5 ± 3.4	28.4-40.8	28.05 ± 2.97	25.45 - 36.32
APPLIANCE	Hyrax (4 bands)	15				
	Hyrax (2 bands)	9				
	Haas	11				
	Bonded	9				

Table II. - Comparison of initial and final measurements of the RME group and Non- Expansion Group with 2 Tailed Paired T-Test.

	Expansion			Non Expansion			Intra-examiner reliability	Differences btw means of groups: Non-Exp minus Exp	
Measurement	Initial	Final	Δ Mean ± SD	Initial	Final	Δ Mean ± SD		Initial	Final
Maxillary Volume(cc)	20.82 ± 5.10	30.48 ±5.24	9.66 ± 0.14	23.83± 5.62	30.72± 5.33	6.89 ± 0.29	0.86	3.01	0.24
Anterior Volume(cc)	9.48 ± 2.67	12.74± 2.27	3.26 ± 0.4	11.02±3.07	12.71± 2.28	1.69 ± 0.79	0.88	1.54	-0.03
Posterior Volume(cc)	12.01± 2.98	17.74± 3.54	5.73 ± 0.56	13.75± 3.64	18.01± 3.45	4.26 ± 0.19	0.90	1.74	0.27
Intercanine (mm)	21.74± 2.53	24.91± 1.73	3.17 ± 0.8	22.99± 1.50	24.74± 1.32	1.75 ± 0.18	0.93	1.25	-0.17
Intermolar (mm)	31.88± 2.02	34.90± 2.38	3.02 ± 0.36	34.28± 1.74	35.03± 2.05	0.75 ± 0.31	0.96	2.4	0.13
Anterior-posterior (mm)	49.10± 3.26	51.48± 3.01	2.38 ± 0.25	49.53± 2.63	50.81± 2.85	1.28 ± 0.22	0.99	0.43	-067

*P≤0.05

TABLE III: Testing significance in the changes in maxillary volume among the experimental group

Measurements	Initial	Final	P-value
Maxillary volume	20.82 ± 5.10	30.48 ±5.24	0.000
Anterior volume	9.48 ± 2.67	13.74± 2.27	0.000
Posterior volume	12.01± 2.98	17.74± 3.54	0.002
Inter Canine	21.74± 2.53	24.91± 1.73	0.000
Inter Molar	31.88± 2.02	34.90± 2.38	0.005
Anterio-posterior	49.10± 3.26	51.48± 3.01	0.006

*P≤0.05
**paired sample t-test

Table IV: Testing significance in the changes in maxillary volume among the control group

Measurements	Initial	Final	P-value
Maxillary volume	23.83± 5.62	30.72± 5.33	0.002
Anterior volume	11.02± 3.07	12.71± 2.28	0.000
Posterior volume	13.75± 3.64	18.01± 3.45	0.005
Inter Canine	22.99± 1.50	24.74± 1.32	0.000
Inter Molar	34.28± 1.74	35.03± 2.05	0.014
Anterio-posterior	49.53± 2.63	50.81± 2.85	0.040

*P≤0.05
** paired sample t-test

Table V: Testing for significance between initial and final volumes of experimental and control group

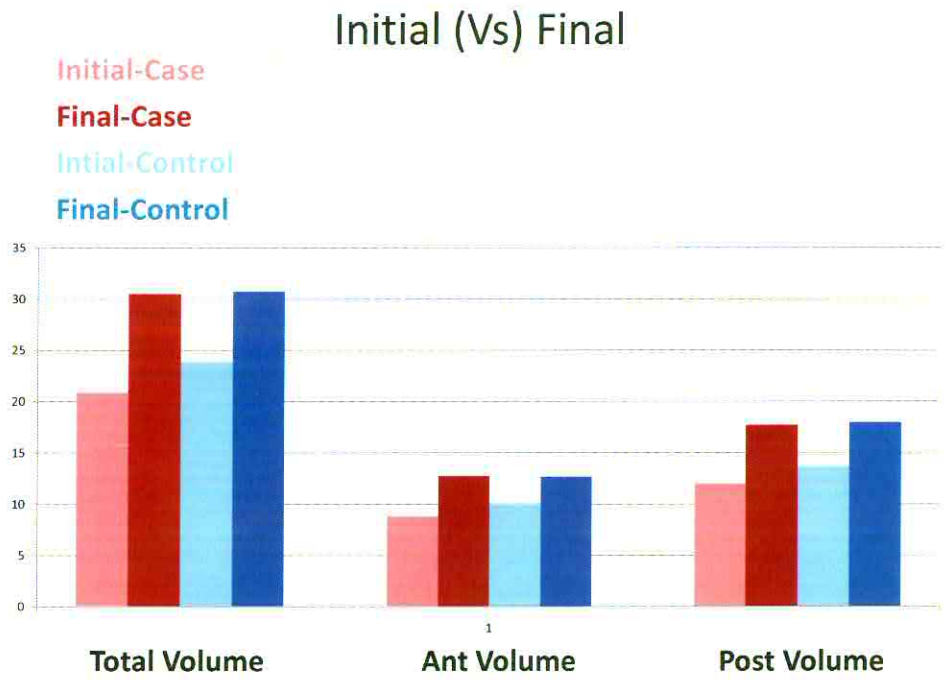
	Initial (experimental)	Initial (control)	P-value	Final (experimental)	Final (control)	P-value
Maxillary volume	20.82 ± 5.10	23.83± 5.62	0.007	30.48 ±5.24	30.72± 5.33	0.756
Anterior volume	9.48 ± 2.67	11.02± 3.07	0.018	13.74± 2.27	12.71± 2.28	0.990
Posterior volume	12.01± 2.98	13.75± 3.64	0.011	17.74± 3.54	18.01± 3.45	0.628
Inter Canine	21.74± 2.53	22.99± 1.50	0.005	24.91± 1.73	24.74± 1.32	0.562
Inter Molar	31.88± 2.02	34.28± 1.74	0.000	34.90± 2.38	35.03± 2.05	0.683
Anterio-posterior	49.10± 3.26	49.53± 2.63	0.578	51.48± 3.01	50.81± 2.85	0.241

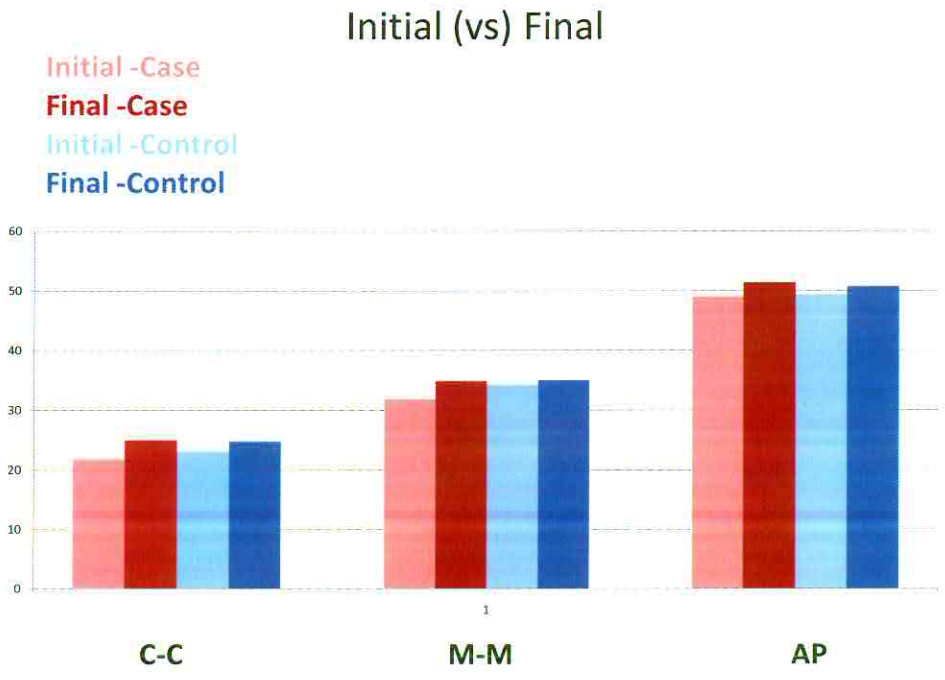
*P≤0.05
**independent sample t-test

Table VI: Testing for significance in the changes in initial and final volume between experimental and control group

	Δ mean ± sd (experimental)	Δ mean ± sd (control)	P-value
Maxillary volume	9.66 ± 0.14	6.89 ± 0.29	0.005
Anterior volume	4.26 ± 0.4	1.69 ± 0.79	0.008
Posterior volume	5.73 ± 0.56	4.26 ± 0.19	0.021
Inter Canine	3.17 ± 0.8	1.75 ± 0.18	0.000
Inter Molar	3.02 ± 0.36	0.75 ± 0.31	0.001
Anterio-posterior	2.38 ± 0.25	1.28 ± 0.22	0.006

*$p \leq 0.05$
** independent sample t-test


Initial (Vs) Final
Initial-Case
Final-Case
Intial-Control
Final-Control
35
30
25
20
15
10
5
0
1
Total Volume
Ant Volume
Post Volume


Initial (vs) Final
Initial -Case
Final -Case
Initial -Control
Final -Control
60
50
40
30
20
10
0
1
C-C
M-M
AP

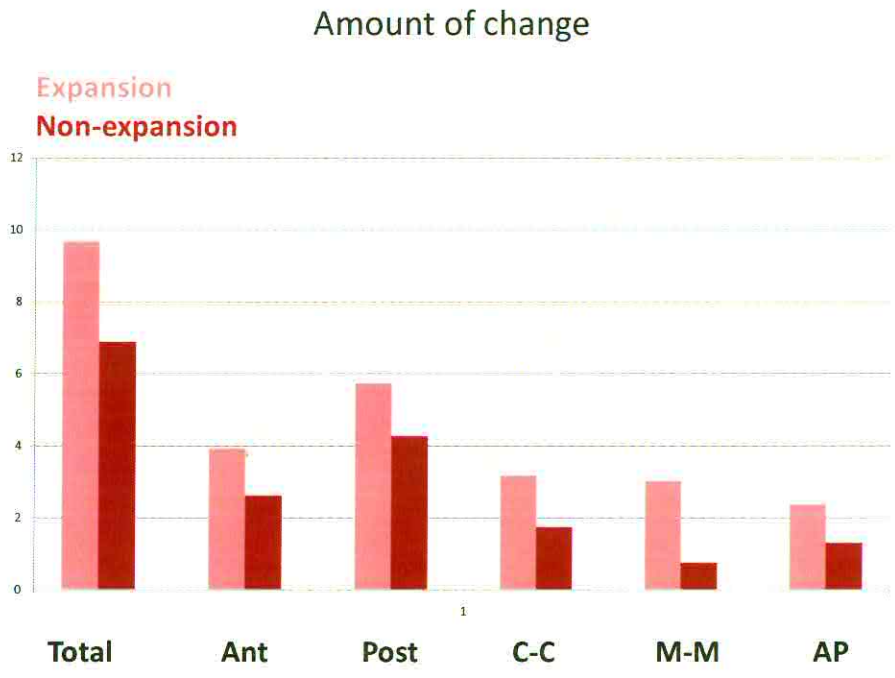

Amount of change
Expansion
Non-expansion
12
10
8
6
4
2
0
1
Total
Ant
Post
C-C
M-M
AP

Fig 1:

Sculpt carefully the teeth at the level of the CEJ,
Sculpt the posteriors, right and left side separately
(tilt the head a little to avoid slicing the other side)



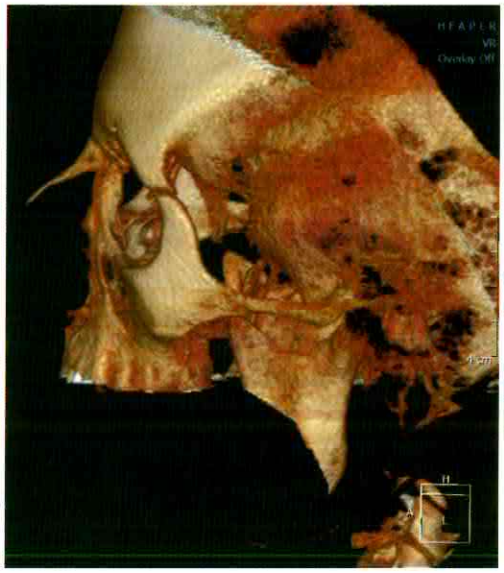


Fig 2a: Orient the head to ANS-PNS in the Sagittal view

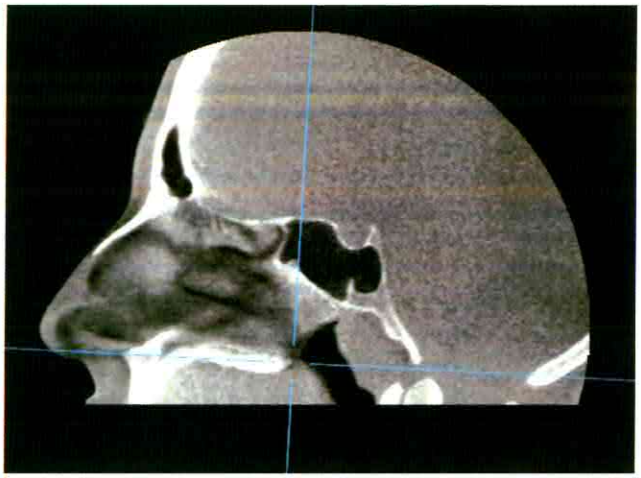


Fig 2b: Orient the head to the Zygomatic arch (key ridge) in the coronal view.

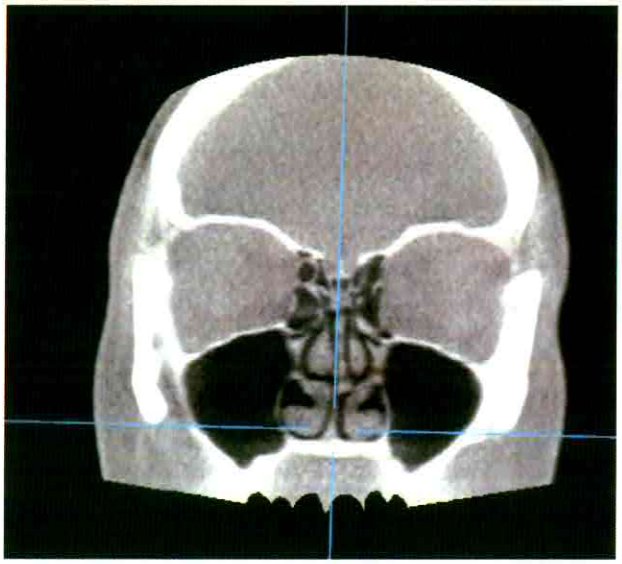
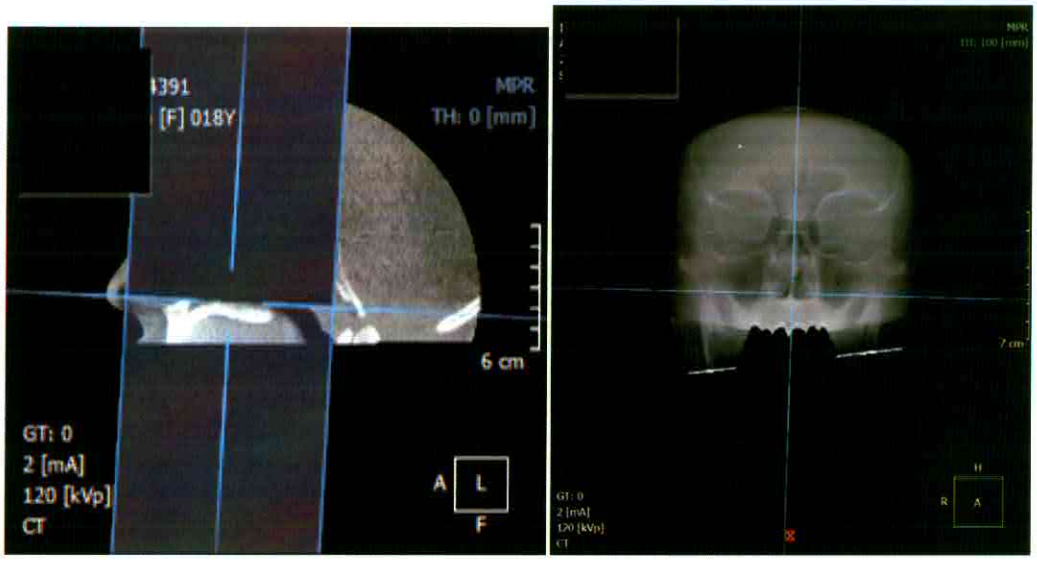
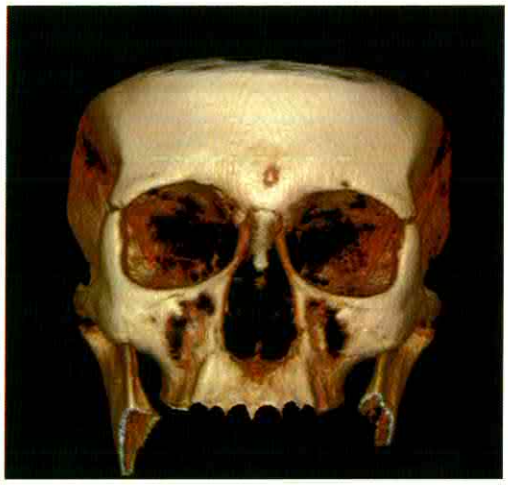


Fig 3a: Increase the slice thickness in the Sagittal view to include the entire maxilla from ANS-PNS and view obtained in coronal plane.



Sagittal Plane Coronal Plane

Fig 3b: In the coronal view, change to volume rendering to get a good view of the Zygomatic arch. Sculpt at the level of the most prominent point of the key ridges on either side using the sculpting tool.



Resultant section

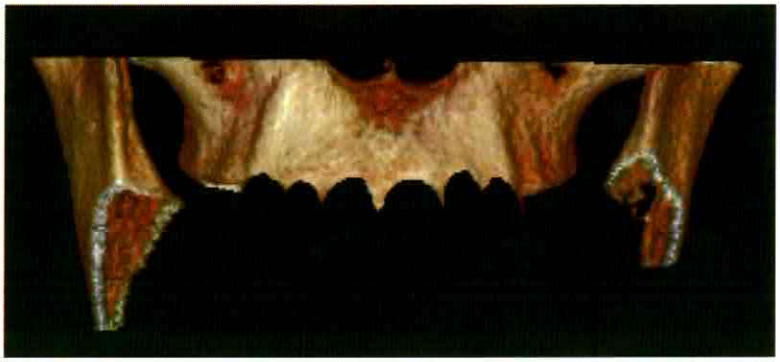


Fig 4: In the volume rendering mode, rotate the head to view the palate and sculpt all remaining structures and soft tissue.

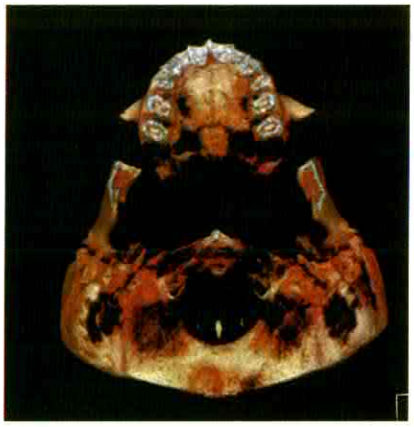


Fig 5: Resultant image after sectioning



Fig 6: 6mm posterior to incisive canal perpendicular to midpalatal is measured and a slice is made along the entire volume of the maxilla

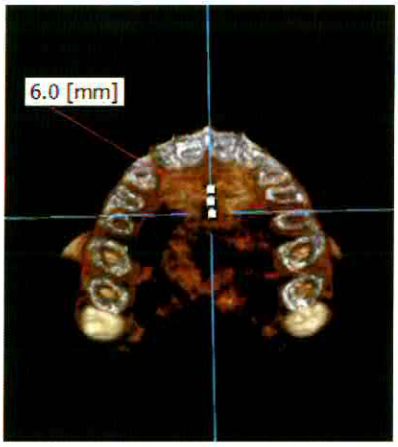


Fig 7: The segmented posterior maxilla





Fig 8: Segmented anterior maxilla

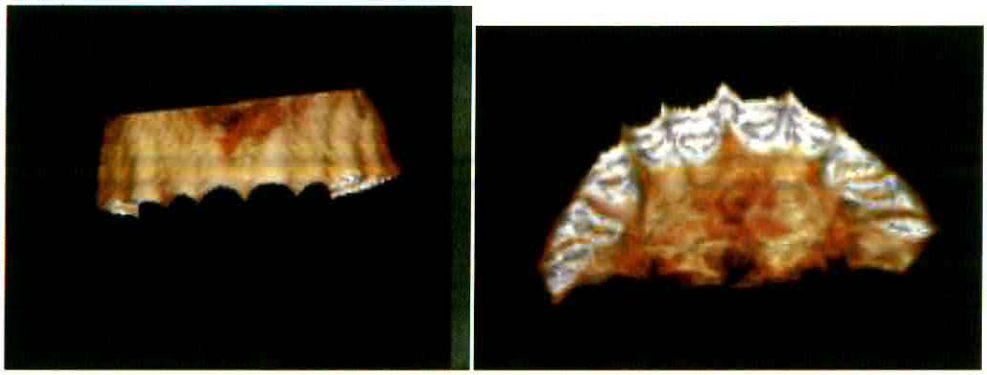


Fig 9a: Measuring intermolar and intercanine width

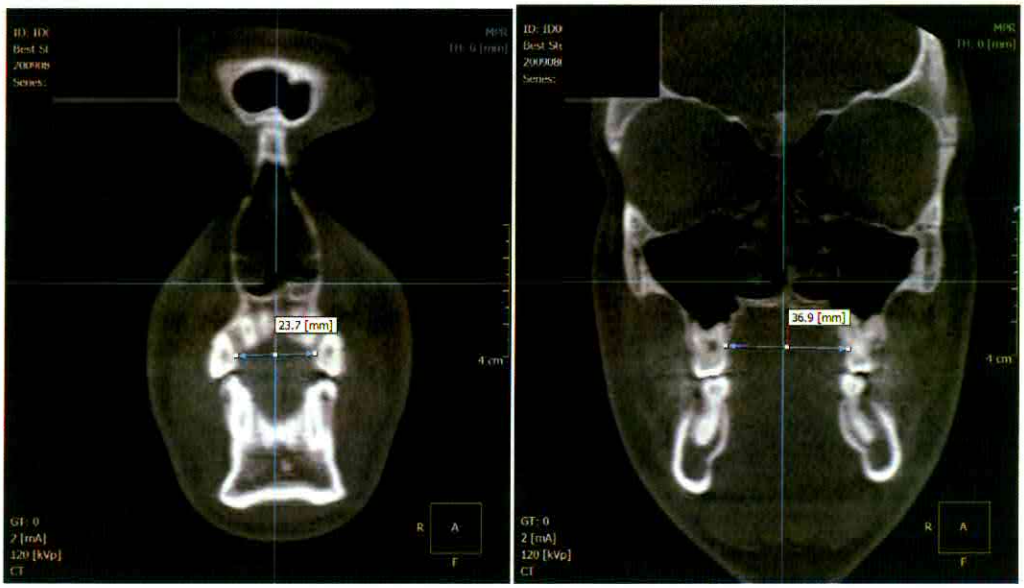
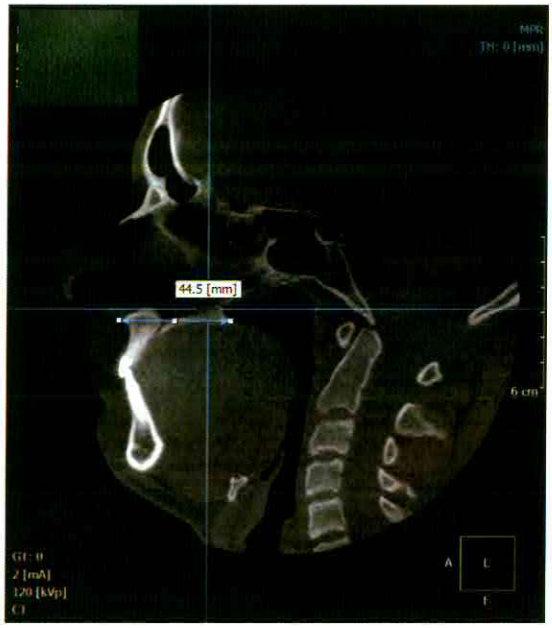


Fig 9b: Measuring ANS-PNS



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.

Please note that this only applies to existing data.

Prospective data is NOT included in this exemption - De-identified pre-existing data to be collected on

12/07/2010 and after are NOT covered by this exemption.

Responsible Investigator: **J. Martin Palomo**

Department: **Dental Orthodontics**

IRB Protocol Number: **20101120**

Title: ***Retrospective Case Control Study to Measure the Change in the Volume of the Maxilla Before and After Orthodontic Treatment With and Without Rapid Palatal Expansion Using CBCT***

Co-Investigator: **Aparna Chitharanjan**

Exemption Date: December 6, 2010

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, #657

APPENDIX II- RAW DATA

ID	B Date	Sex	S Date	F Date	Rx Time	Exp	Initial VM	Int V ant	Int Vpost	Final VM	Fin V ant	Fin Vpos	Int C-C	Int M-M	Int A-P	Fin C-C	Fin M-M	Fin A-P
GA4	7/13/1994	M	7/10/2007	7/10/2009	40	1	24.5165	10.6583	13.8582	33.0986	14.0865	19.0121	23.7	32	46.1	26.8	36.7	48.4
DA134	8/4/1990	M	9/14/2006	9/14/2008	50	1	17.8381	6.88376	10.9543	40.2648	16.0067	24.2581	16.4	27.6	50.9	22.5	28.8	54
GI31	2/23/1995	M	8/24/2006	8/24/2008	51	1	14.4523	5.96265	8.48965	32.913	9.99	22.923	22.7	29.3	50.59	24.9	33.9	54.4
ST219	11/12/1994	M	8/16/2007	8/16/2009	39	1	20.132	9.6176	10.5144	32.5469	13.9318	18.6151	22.8	28.6	52.6	24.3	31.8	54.8
GO112	12/23/1994	F	10/29/2007	10/29/2009	37	1	29.5015	13.2094	16.2921	38.9845	15.0075	23.977	21.3	33.6	51.4	23.9	35	54.2
AL96	3/13/1996	M	8/1/2007	8/1/2009	39	1	19.2104	9.57543	9.63497	31.7719	11.8867	19.8832	27.7	34.6	51.6	26.4	38	54.8
WI298	5/7/1994	M	10/15/2009	10/15/2011	13	1	23.0976	5.835	17.2626	36.9775	15.9564	21.0211	26.5	30.2	50	29.5	33.9	53.4
DU68	4/11/1993	M	10/31/2007	12/31/2009	37	1	25.3142	9.0086	16.3056	34.7612	15.2498	19.5114	20.7	30.8	51.7	25.4	39.5	53.2
CA179	7/17/1991	F	7/6/2006	1/6/2009	52	1	17.1685	6.1256	11.0429	27.5396	11.4442	16.0954	19.5	32.8	46.8	22.2	33.5	48.4
MC148	10/19/1995	M	10/9/2007	10/9/2009	37	1	25.3964	13.9864	11.41	32.7382	14.6306	18.1076	18.7	33.4	54.9	24.3	34.4	55.5
GA38	5/26/1993	F	12/14/2006	12/14/2008	47	1	26.3217	10.1162	16.2055	33.0168	13.2965	19.7203	23.1	32.34	47.8	27.4	36.4	51.1
SI32	2/2/1994	F	10/9/2006	10/9/2008	49	1	23.5425	8.9188	14.6237	26.8543	11.9832	14.8711	19.2	29.9	46.7	24.2	33.5	48
CH87	1/15/1991	F	8/10/2006	8/10/2008	51	1	20.1902	7.6085	12.5817	38.8665	16.1088	22.7577	21.7	33.61	50.73	25.1	36.9	53.8
WE131	11/30/1993	M	8/3/2006	8/3/2008	51	1	15.8265	5.97986	9.84664	24.517	10.5186	13.9984	25.4	34.32	47.28	27.63	40	50.6
AL105	4/3/1997	F	10/27/2008	12/27/2010	25	1	16.9853	6.00923	10.9761	32.9854	12.0096	20.9758	19.5	31.8	47.2	23.1	34	50.4
AL99	6/15/1996	M	8/5/2008	8/5/2010	27	1	18.9095	8.63768	10.2718	28.0483	10.783	17.2653	19.6	31.4	47.4	23.7	34.6	51.5
SH119	8/14/1992	M	8/29/2006	8/29/2009	51	1	24.1489	9.9764	14.1725	33.0063	14.0367	18.9696	26.7	34.32	48.8	28.4	35.9	52
GE46	9/28/1994	F	10/29/2008	10/29/2010	25	1	29.44425	13.9616	15.4827	34.0928	12.8775	21.2153	20.9	30.6	46.9	23.8	32.1	48
GI54	10/27/1994	F	9/13/2006	9/13/2008	50	1	23.3596	10.6174	12.7422	26.9642	11.8542	15.11	18.31	32.37	46.09	24.2	35.6	47.4
RU43	12/17/1991	F	9/26/2006	9/20/2008	50	1	19.5241	7.1542	12.3699	34.6136	14.4693	20.1443	20.92	34.49	43.5	23	38.1	45.9
VR2	10/22/1995	M	10/7/2008	10/7/2010	25	1	22.5734	9.12196	13.4514	29.1967	12.1607	17.036	20.9	28.5	55.4	26.3	33.5	52.6
PI70	10/10/1995	M	10/20/2008	10/20/2010	25	1	27.0901	13.6756	13.4145	33.7168	14.3411	19.3757	18.5	30	46.3	24.2	33.3	50.8
SE61	8/13/1992	M	8/22/2006	1/18/2009	51	1	17.3618	7.39521	9.96659	29.6951	12.9216	16.7735	25	32.8	46.7	25	35.4	53.4
SA130	5/14/1996	M	8/19/2008	8/19/2010	27	1	18.8374	7.97626	10.8611	25.0624	10.874	14.1884	22.1	32.2	51.7	25.5	35	51.3
SA135	5/5/1994	M	9/4/2008	9/4/2010	26	1	29.5207	13.9875	15.5332	36.8339	15.2007	21.6332	22.7	30.8	53.4	25.4	33.9	53.3
TE29	6/1/1995	M	9/4/2008	9/4/2010	26	1	19.8281	8.95409	10.874	28.5138	11.0585	17.4553	19.2	28.7	52	23.1	30.9	53.8
HO164	5/7/1993	M	10/9/2006	10/9/2008	49	1	15.3778	6.0012	9.3766	33.4994	15.3201	18.1793	23.19	33.65	54.24	25.7	37.3	59.8
LU17	10/19/1993	M	11/22/2006	11/22/2008	48	1	14.071	5.3839	8.6871	25.0801	10.0329	15.0472	20.61	32.07	46.64	23.1	31.1	46.2
HA142	12/9/1991	F	9/7/2006	9/7/2008	24	1	21.1219	10.4207	10.7012	34.0239	16.8697	17.1542	18.5	31.4	40.9	24.7	34.6	51
HO210	10/22/1995	F	8/26/2008	12/26/2010	27	1	23.8947	10.6192	13.2755	26.9325	12.5596	14.3729	22	31.1	46.6	25.3	35.8	49
LO75	2/18/1993	M	7/20/2006	9/20/2008	52	1	15.1046	5.9154	9.1892	25.1535	10.7087	14.4448	21.31	31.73	45.11	23.5	33.3	47
GO99	4/5/1994	F	10/19/2006	10/19/2008	49	1	15.4667	6.58486	8.88184	27.9665	10.1687	17.7978	24.04	34.04	47.71	24.3	36.9	49.8
MU22	2/15/1993	M	10/5/2006	2/5/2009	49	1	15.4439	5.97189	9.47201	26	11.1256	14.5614	23.44	29.62	53.43	26.1	35.5	55.1
RO190	7/7/1993	F	10/31/2006	12/31/2008	49	1	15.4732	5.92359	9.54961	28.5868	12.4133	16.1735	22.18	31.52	51.78	24.8	34.5	51.5
BA219	12/25/1994	M	8/7/2008	8/7/2010	27	1	28.6436	13.1562	15.4874	29.9334	14.3065	15.6269	22.5	33.7	53.9	27.1	38.4	56.1
BR18	2/13/1996	F	10/30/2008	10/30/2010	25	1	17.1591	6.20171	10.9574	21.0241	7.99292	13.0312	24.4	31.8	49.5	24.1	33.8	50.1
MC169	5/26/1994	M	10/20/2008	10/20/2010	25	1	15.9863	6.1256	9.8607	28.6428	10.1354	18.5074	22.2	33.8	51	26.3	35.1	54.4
BA132	3/2/1994	F	8/31/2006	8/31/2008	51	1	10.9672	3.04143	7.92577	22.7899	10.0288	12.7611	23.36	29.17	47.76	23.3	32.8	50
ME43	3/9/1994	F	9/17/2008	9/17/2010	36	1	26.5606	11.89	14.6706	28.2466	12.4203	15.8263	20.5	34	49.1	24.1	35.2	51.1
SF1	10/26/1993	F	12/21/2007	12/21/2009	35	1	18.9765	8.7643	10.2122	30.8743	14.9864	15.8879	22.7	33.5	49.9	24.5	38.6	50.9
PU9	2/10/1993	F	10/11/2007	10/11/2009	37	1	17.7717	7.94009	9.83161	19.135	7.6658	11.4692	22.9	33.8	48.3	26.9	36.1	50.9
LI76	5/4/1994	M	11/26/2007	11/26/2009	36	1	20.8753	10.8753	10	32.0985	14.9863	17.1122	20.6	35	43.3	26.7	35.6	46
CZ3	6/11/1995	M	8/30/2007	8/30/2009	39	1	19.78	10.8062	8.9738	21.231	10.8956	10.3354	16.2	28	46.7	20.6	30.5	49.1
HA344	8/31/1994	F	11/5/2007	11/5/2009	36	1	33.5807	11.4631	22.1176	42.7223	15.4788	27.2435	22.4	33.9	50.1	24.8	35.8	52.1

CH78	6/4/1992	M	7/12/2006	7/12/2008	53	2	21.8558	8.95489	12.9009	23.2433	9.1478	14.0955	23.5	35	53.9	24.1	36.1	53.78
IS22	7/18/1995	M	9/24/2007	9/24/2009	39	2	22.98	12.8732	10.1068	29.2982	12.5717	16.7265	24	37	47.5	28.2	36.4	49.6
GR162	4/26/1995	M	5/17/2007	5/17/2009	43	2	25.7126	12.5346	13.178	31.0552	15.4851	15.5701	20.9	36	44.9	23.9	36.5	47
MA322	12/6/1990	M	8/16/2007	8/16/2009	40	2	30.8676	13.098	17.7696	30.469	13.6459	16.8231	19.6	36.6	53.8	24.8	38.7	56.8
DE105	1/28/1994	M	7/10/2007	7/10/2009	41	2	32.1969	13.6087	18.5882	37.9432	16.7029	21.2403	23.1	35.5	48.5	24.1	36.1	50.5
RO223	2/27/1994	M	10/3/2007	10/3/2009	38	2	24.6327	11.0495	13.5832	26.8088	12.7698	14.039	24.3	33	49.2	26.5	36.9	48.7
BA175	3/30/1994	F	7/30/2007	11/30/2009	41	2	20.4671	8.57649	11.8906	25.0208	10.0232	14.9976	20.8	29.6	47.5	23.8	30.7	49.9
GR153	12/29/1992	F	7/5/2006	12/31/2008	53	2	14.7308	5.82926	8.90154	21.4384	8.90495	12.5335	23.12	34.02	47.98	24.53	34.31	49.11
MA316	3/22/1995	M	10/18/2007	10/18/2009	38	2	22.5976	10.1129	12.4847	24.4672	10.3508	14.1164	23.45	32.12	48.65	24.6	33.9	49.4
KN15	3/26/1994	M	8/21/2007	8/21/2009	40	2	25.4125	10.9927	14.4198	35.8542	13.7534	22.1008	21.8	34.7	49.1	25.5	37.6	50.6
RO228	12/28/1993	M	10/29/2007	10/29/2009	38	2	25.6163	12.0112	13.6051	33.1017	14.771	18.3307	24.5	38	48.7	26.5	37.6	48.5
KA94	12/7/1994	M	9/19/2007	9/19/2009	39	2	24.789	9.75118	15.0378	33.9468	13.7117	20.2351	22.3	33.4	46.6	24.6	37.6	51.1
KO82	11/20/1993	M	8/27/2007	10/27/2009	40	2	25.8273	9.72916	16.0981	36.9319	14.4001	22.5318	20.4	32.2	51.9	22.3	32.4	52.5
PE142	10/26/1993	M	11/12/2007	11/12/2009	37	2	33.3501	13.6264	19.7237	39.5755	15.4046	24.1709	23.3	36.9	51.8	24.9	37.3	52.2
SI56	4/13/1992	M	10/25/2007	4/25/2010	38	2	20.1793	9.4002	10.7791	29	13.9112	15.0055	24.3	35.2	51.6	24.9	36.8	53.8
WA167	7/3/1991	F	7/17/2007	5/17/2010	41	2	26.7483	12.306	14.4423	34.2808	13.5858	20.695	21.1	29.7	47.5	25.1	30.4	46.2
TO65	3/2/1993	M	10/22/2007	10/22/2009	38	2	20.4169	10.485	9.9319	31.1983	13.2559	17.9424	25.1	33.6	50.8	26.4	36	53.8
WE140	12/23/1994	F	9/26/2007	9/26/2009	39	2	20	8.9906	10.8848	24.7977	9.26503	15.5327	25.3	33.23	48.02	26.3	34.8	49.6
HU99	8/10/1994	M	9/19/2007	9/19/2009	39	2	16.0986	7.01922	9.07938	22.9133	10.0669	12.8464	20.3	34	48.5	21.9	34.2	51.53
WA172	9/15/1991	F	8/29/2007	8/29/2009	40	2	22.7732	10.5754	12.1978	24.2885	10.4686	13.8199	23.1	33.2	44.1	23.1	33	44.2
MA329	4/16/1993	M	11/26/2007	11/26/2009	37	2	24.2371	9.72031	14.5168	34.3445	12.5596	21.7849	23.9	33.6	47.4	25.9	35.1	47.6
PA148	8/24/1995	F	10/17/2007	10/17/2009	38	2	18.978	7.36237	11.6156	24.8946	10.6006	14.294	20.8	31.7	46.9	24.2	30.8	45.9
GL15	8/20/1993	F	10/4/2006	10/4/2008	50	2	16.8949	6.52538	10.3695	22.9059	9.51821	13.3877	20.6	33.81	48.97	23.7	33.3	51.3
PO67	11/6/1991	M	11/6/2006	11/6/2008	49	2	15.4794	6.83527	8.64413	28.7718	10.9567	17.8151	22.9	33.6	48.2	22.1	34.4	51.5
ED12	10/17/1991	F	10/11/2006	10/11/2008	50	2	15.0694	5.002	10.0674	22.6904	9.17056	13.5198	22.28	34.28	45.88	25	33.3	47.8
PE184	6/15/1996	F	7/13/2009	7/13/2011	17	2	30.8129	11.0515	19.7614	34.4636	13.3974	21.0662	21.8	33.3	49.7	25.2	33.6	48.7
HA305	1/18/1993	F	7/7/2008	7/7/2010	29	2	31.6283	12.7899	18.8384	35.7032	13.4282	22.275	23.6	34.4	50.5	23.5	33.8	50.3
SP60	7/10/1996	M	8/27/2008	8/27/2010	28	2	20.0336	8.6323	11.4013	29.9941	13.3119	16.6822	22.6	33.4	49.6	26	37.9	52.5
KO115	8/22/1994	M	9/4/2008	9/4/2010	27	2	17.1406	7.49594	9.64466	26.138	11.3683	14.7697	24.3	35.6	51.6	26.9	35	56.4
GI59	3/3/1994	M	11/3/2008	11/3/2010	25	2	26.7962	11.7331	15.0631	29.3926	13.2567	16.1359	24.2	36.4	48.9	24.3	34.9	53.1
TR63	8/4/1994	F	7/9/2008	7/9/2010	29	2	31.6685	14.4911	17.1774	31.9409	13.6283	18.3126	21.8	34	53.7	23.3	34.2	53.1
BE173	1/24/1997	M	10/30/2008	10/30/2010	26	2	26.5517	11.6493	14.9024	33.2309	13.3425	19.8884	22.4	32.4	47.4	24.8	31.6	50.7
JA112	10/21/1993	F	8/27/2007	8/27/2009	40	2	32.2399	11.9807	20.2592	32.4868	12.8671	19.6197	23.6	36.4	48.8	23.9	37.6	49
KN17	2/3/1995	M	10/13/2008	10/13/2010	26	2	28.7465	12.4419	16.3046	38.4051	17.7863	20.6188	23.2	34.2	57.3	24.7	37.9	59.2
LE17	6/1/1994	F	10/17/2006	10/17/2008	50	2	19.8318	7.50311	12.3287	36.1912	13.9987	22.1925	23.9	32.83	49.98	23.8	34.5	50.9
GR123	4/23/1993	M	7/13/2006	7/13/2008	53	2	19.969	9.29959	10.6694	25.1712	11.5693	13.6019	26.3	36.3	48.6	26.4	36.9	50.3
SM101	4/10/1994	F	10/26/2006	10/26/2008	50	2	15.1663	6.83436	8.33194	30.0202	12.2522	17.768	23.8	35.1	47.1	24	34.9	49.9
SP65	12/7/1994	F	10/12/2009	10/12/2011	14	2	15.3087	6.638	8.6707	27.6754	11.24	16.4354	25.5	34.6	49.9	25.7	33.3	49.7
HU68	6/9/1993	F	8/16/2006	8/16/2008	52	2	21.259	8.69359	12.5654	36.7982	14.4241	22.3741	22.4	34.7	48.9	22.8	35.1	50.2
MO186	4/7/1994	F	7/7/2008	7/7/2010	29	2	22.9856	8.4352	14.5504	28.8765	9.7654	19.1111	23.4	35.3	53.1	25.5	34.1	52
DU69	5/10/1994	M	10/2/2007	10/2/2009	37	2	29.0789	13.5984	15.4805	40.9843	17.063	23.9213	23.2	35.3	53.1	25.5	36.1	53.9
MO186	07/04/1994	F	07/07/2008	9/27/2010	26	2	31.7684	10.8764	20.892	32.7446	11.6794	21.0652	23.4	35.3	53.1	25.5	34.1	51
VO22	21/09/1995	M	15/10/2008	8/18/2010	22	2	27.8347	11.6758	16.1589	31.9876	12.9864	19.0012	23.2	33.8	48.9	24.6	34.9	49.9
MO200	08/03/1994	F	08/10/2008	10/19/2010	24	2	32.2367	11.0875	21.1492	40.4929	17.0134	23.4795	24.12	34.9	51.1	25	36.52	52.2
KA123	25/12/1994	F	25/09/2008	10/25/2010	23	2	31.5432	12.5873	18.9559	35.7877	13.8743	21.9134	23.6	36.1	46.2	24.2	37.98	47.6

APPENDIX III: Results from SPSS

Group Statistics

	Exp	N	Mean	Std. Deviation	Std. Error Mean
Initial VM	With Expander	44	20.8260534	5.10189401	.76913946
	Without expander	45	24.0113756	5.67090012	.84536788
Initial Vant	With Expander	44	8.8190441	2.77817007	.41882490
	Without expander	45	10.1436649	2.41201103	.35956137
Initial Vpost	With Expander	44	12.0070093	2.97728920	.44884323
	Without expander	45	13.8649418	3.68100084	.54873121
Int C-C	With Expander	44	21.7445455	2.53217753	.38174013
	Without expander	45	23.0015556	1.48858987	.22190588
Int M-M	With Expander	44	31.8829545	2.02514608	.30530226
	Without expander	45	34.3175556	1.74937152	.26078091
Int A-P	With Expander	44	49.1013636	3.26004608	.49147044
	Without expander	45	49.4528889	2.65089661	.39517233

Independent sample T-Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Initial VM	Equal variances assumed	.922	.340	-2.784	87	.007	-3.18532215	1.14426998	-5.45968264	-.91096165
	Equal variances not assumed			-2.787	86.409	.007	-3.18532215	1.14290085	-5.45718059	-.91346370
Initial Vant	Equal variances assumed	.797	.374	-2.404	87	.018	-1.32462080	.55111508	-2.42002169	-.22921990
	Equal variances not assumed			-2.400	84.751	.019	-1.32462080	.55199518	-2.42218165	-.22705995
Initial Vpost	Equal variances assumed	2.554	.114	-2.615	87	.011	-1.85793246	.71060524	-3.27033732	-.44552760

	Equal variances not assumed			-2.621	84.067	.010	-1.85793246	.70891903	-3.26767932	-.44818560
Int C-C	Equal variances assumed	9.222	.003	-2.863	87	.005	-1.25701010	.43911750	-2.12980368	-.38421652
	Equal variances not assumed			-2.847	69.243	.006	-1.25701010	.44155152	-2.13782603	-.37619417
Int M-M	Equal variances assumed	2.067	.154	-6.074	87	.000	-2.43460101	.40085458	-3.23134289	-1.63785913
	Equal variances not assumed			-6.064	84.616	.000	-2.43460101	.40151731	-3.23297723	-1.63622479
Int A-P	Equal variances assumed	3.264	.074	-.559	87	.578	-.35152525	.62917800	-1.60208465	.89903415
	Equal variances not assumed			-.557	82.765	.579	-.35152525	.63063806	-1.60589159	.90284109

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Initial VM	20.8260534	44	5.10189401	.76913946
	Final VM	30.4891068	44	5.23811160	.78967504
Pair 2	Initial Vant	8.8190441	44	2.77817007	.41882490
	Final Vant	12.7450384	44	2.27229134	.34256081
Pair 3	Initial Vpost	12.0070093	44	2.97728920	.44884323
	Final Vpost	17.7369548	44	3.53965303	.53362277
Pair 4	Int C-C	21.7445455	44	2.53217753	.38174013
	Final C-C	24.9120455	44	1.73343667	.26132541
Pair 5	Int M-M	31.8829545	44	2.02514608	.30530226
	Final M-m	34.8977273	44	2.37961191	.35873999
Pair 6	Int A-P	49.1013636	44	3.26004608	.49147044
	Final A-P	51.4795455	44	3.01280828	.45419794

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Initial VM & Final VM	44	.538	.000
Pair 2	Initial Vant & Final Vant	44	.449	.002
Pair 3	Initial Vpost & Final Vpost	44	.533	.000
Pair 4	Int C-C & Final C-C	44	.703	.000
Pair 5	Int M-M & Final M-m	44	.712	.000
Pair 6	Int A-P & Final A-P	44	.795	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Initial VM - Final VM	-9.66305341	4.970735643	.74936659	-11.17429517	-8.151811685	-12.895	43	.000
Pair 2	Initial Vant - Final Vant	-3.92599432	2.686455224	.40499837	-4.74275136	-3.109237227	-9.694	43	.000
Pair 3	Initial Vpost - Final Vpost	-5.72994545	3.188559230	.48069339	-6.69935606	-4.760534845	-11.920	43	.000
Pair 4	Int C-C - Final C-C	-3.16750000	1.802417144	.27172461	-3.71548490	-2.619515100	-11.657	43	.000
Pair 5	Int M-M - Final M-m	-3.01477273	1.703495022	.25681154	-3.53268255	-2.496862900	-11.739	43	.000
Pair 6	Int A-P - Final A-P	-2.37818182	2.022425755	.30489215	-2.99305545	-1.763308119	-7.800	43	.000

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Initial VM	24.0113756	45	5.67090012	.84536788
	Final VM	30.8383342	45	5.32352359	.79358404
Pair 2	Initial Vant	10.1436649	45	2.41201103	.35956137
	Final Vant	12.7389989	45	2.26109089	.33706353
Pair 3	Initial Vpost	13.8649418	45	3.68100084	.54873121
	Final Vpost	18.0974842	45	3.46176206	.51604902
Pair 4	Int C-C	23.0015556	45	1.48858987	.22190588
	Final C-C	24.7228889	45	1.30580282	.19465759
Pair 5	Int M-M	34.3175556	45	1.74937152	.26078091
	Final M-m	35.0913333	45	2.07759433	.30970948
Pair 6	Int A-P	49.4528889	45	2.65089661	.39517233
	Final A-P	50.7448889	45	2.85936549	.42624904

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Initial VM & Final VM	45	.713	.000
Pair 2	Initial Vant & Final Vant	45	.692	.000
Pair 3	Initial Vpost & Final Vpost	45	.688	.000
Pair 4	Int C-C & Final C-C	45	.538	.000
Pair 5	Int M-M & Final M-m	45	.711	.000
Pair 6	Int A-P & Final A-P	45	.831	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Initial VM - Final VM	-6.82695867	4.17573605	.62248198	-8.08148866	-5.57242867	-10.967	44	.000
Pair 2	Initial Vant - Final Vant	-2.59533400	1.83827156	.27403334	-3.14761192	-2.04305608	-9.471	44	.000
Pair 3	Initial Vpost - Final Vpost	-4.23254244	2.83009744	.42188602	-5.08279785	-3.38228704	-10.032	44	.000
Pair 4	Int C-C - Final C-C	-1.72133333	1.35293385	.20168347	-2.12779966	-1.31486701	-8.535	44	.000
Pair 5	Int M-M - Final M-m	-.77377778	1.48517414	.22139669	-1.21997349	-.32758207	-3.495	44	.001
Pair 6	Int A-P - Final A-P	-1.29200000	1.61425412	.24063880	-1.77697563	-.80702437	-5.369	44	.000

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