Title
Three dimensional analyses of the effects of rapid maxillary expansion

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Publication Date
2007

Peer reviewed|Thesis/dissertation

Three Dimensional Analyses of the Effects of Rapid Maxillary Expansion

by

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THESIS

Submitted in partial satisfaction of the requirements for the degree of

MASTERS OF SCIENCE

in

ORAL AND CRANIOFACIAL SCIENCES

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA

San Francisco

[redacted]

Date University Librarian

DEDICATION

I would like to dedicate this thesis to my wonderful husband, Jimmy. He was a constant source of love and support throughout my entire educational career. I couldn't have done it without him.

ACKNOWLEDGEMENTS

I would like to express my gratitude to the team that made this thesis possible.

Dr. John Huang was instrumental in the development of this study and production of my poster. In addition, he was the expert in the field of CBCT and research methodology.

Dr. Art Miller provided positive reinforcement, a shoulder to cry on, and a challenging approach to look at the project as an opportunity to learn about myself.

Dr. Gerald Neslon provided the essential clinical view point and feedback needed in this type of study. Furthermore, he has an invaluable appreciation for evidence based studies in the field of orthodontics which helped to direct the study.

ABSTRACT

Three Dimensional Analyses of the Effects of Rapid Maxillary Expansion
Natalie Miller, DDS

PURPOSE:

To quantify and understand the immediate and subsequent skeletal and dental effects of rapid maxillary expansion (RME) with the Hyrax appliance using cone beam computed tomography (CBCT).

METHODS:

Fourteen patients (7 male, 7 female) who were 13-16 years old, with skeletal transverse discrepancies, were treated with a Hyrax expander. Three CBCT scans were taken at specific time points: prior to expansion, immediately following active expansion, and 6 months post-expansion. Multiplanar slices were used to measure: linear transverse dimensions, inclinations of the teeth, and the palatal sutural split.

RESULTS:

Data analysis confirmed RME increased all transverse dimensions of the maxilla except the external nasal floor. Rapid maxillary expansion also produced differences in the amount of expansion decreasing in magnitude from anterior to posterior. All posterior teeth showed large changes in inclination, indicating that increases in transverse dimension are largely due to tipping. Second premolars tipped more than anchor teeth supporting the appliance. Volumetric reconstructions and coronal sections showed a 49% incidence of dehiscence and fenestration.

CONCLUSION:

Rapid maxillary expansion significantly increased transverse dimensions of the maxilla, decreasing in magnitude from anterior to posterior and inferior to superior. Although treatment with the Hyrax appliance leads to splitting of the mid-palatal suture, significant increases in transverse dimension are largely due to tipping and subsequent up-righting of the roots of the dentition. The high incidence of dehiscence and fenestration suggest that the resistance to RME may lie in the circumaxillary sutures in addition to the mid-palatal suture.

TABLE OF CONTENTS

List of Tables

List of Figures

Introduction

Purpose

The purpose of this prospective study was to understand the immediate and subsequent skeletal and dental effects of using the Hyrax appliance on the maxillary complex using three-dimensional conebeam computed tomography (CBCT).

Specific Aims

- Examine the skeletal changes at various transverse levels of the maxilla
- To measure the changes in angulation of the maxillary teeth
- To measure the changes of the supporting buccal and lingual alveolar plates
- To describe the changes in the palatal suture
- Timepoints
    - Before rapid maxillary expansion (RME)
    - Immediately after active expansion
    - 6-months post active expansion

Hypotheses

The null hypotheses are:

- There will be no change in the transverse dimensions of the maxilla
- There will be no change in the angulation of the maxillary teeth following the active phase of expansion
- There will be no change in the angulation of the maxillary teeth after 6 mo retention of RME when compared to the initial scans
- There will be no structural changes in the midpalatal suture

Premise

Rapid maxillary expansion is a valuable treatment modality with a variety of benefits, such as correction of transverse discrepancies, increase of arch length, correction of sagittal discrepancies, and improved nasal breathing.[1-12] The effects of RME have been studied since its first documentation in 1860.[2] Although clinicians concur with the clinical applications of RME, numerous disagreements exist regarding the outcomes of the procedure. The introduction of three-dimensional imaging has provided a means to gain additional information regarding the outcome of RME. This study examined the three-dimensional effects of RME on the dental and skeletal components of the maxilla.

Growth and Development of the Maxillary Complex

Rapid maxillary expansion was first documented by Angell in 1860.[2] Angell designed the appliance to take advantage of the patency of the midpalatal suture and aid in normal development of the maxillary complex. This development is facilitated via separation of the two maxillary segments using the dentition as anchorage points. The hygienic or Hyrax appliance is a fixed appliance with bands on the first molars and premolars connected to a jackscrew with an all wire frame. In order to fully appreciate the mechanism of action of the Hyrax appliance, one must understand the processes of maxillary growth and development.

The maxilla develops entirely by intramembranous ossification. Growth occurs by both apposition of bone at the sutures connecting the maxilla and cranial base, and by surface remodeling.[13] The implant studies carried out by Björk confirmed many of the descriptive findings of other researchers.[14,15] These studies first confirmed that the increase in sagittal length of the maxilla is due to sutural apposition towards the palatine bone as well as apposition on the maxillary tuberosities.[14,15] The prenatal cartilagenous nasal septum is almost completely converted into the vomer and ethmoid bones of the midface leaving only a small anterior portion of cartilage that makes up the adult nasal septum.

Implant studies by Björk also refuted previous work of Enlow and Scott showing that the vertical growth of the maxilla takes place by growth at its processes.[14-17] This downward and forward displacement of the maxilla is due to a combination of several things: apposition at the floor of the orbits, resorptive remodeling of the floor of the nose, and apposition on the oral side of the hard palate.[14] Furthermore, Björk's studies showed that there is differential remodeling of the maxilla with greater resorption on the anterior portion of the nasal surface creating a varying degree of vertical rotation of the maxilla.[15] It has been reported that the vertical length of the maxilla increases 19-26% (9 mm) in females and 32-40% (15 mm) in males from ages 6-18 years.[18]

Much of the literature published on the growth of the maxilla focuses on the sagittal and vertical dimensions of the maxilla, however thorough evaluation of the transverse dimension is also needed. The cranial studies of Keith and Campion[19] were the first studies that looked at the midpalatal suture as a site of transverse growth, stating, "the median palatal suture takes an active role in the transverse growth of the maxilla." Latham originally concluded in 1971 that transverse growth of the hard palate stopped at the age of 3.[20] Later work by Björk,[14] Krebs,[21] Skieller,[22] Snodell,[18] and Korn[23] refuted this claim with implant studies. They showed that the transverse growth of the maxilla at the median suture continued beyond puberty until the completion of growth in other facial sutures.[14,15,21-23] More specifically, the distance and velocity curves representing transverse growth of the midpalatal suture is similar to the growth curve describing body height. It was noted that they both showed a distinct pubertal growth maximum at the same time. After the peak velocity of facial growth, transverse changes in the maxilla are minimal, although statistically significant.[15,23] Growth at the midpalatal suture is thought to continue until the ages of 13-15 years and is later followed by apposition for several years until 18 years of age.[24]

Baumrind[25] and Björk[15] estimated the mean increase in transverse growth of the median suture to be 6.5 mm from the age of 4 years old to adult and 5 mm after age 7 at an average rate of 0.18-0.43 mm/yr. In contrast, the width of the dental arch between the first molars increased only 2 mm on average after the age of 7 years old. Similarly, the width between the canines increased very little with a mean of 0.6 mm from the age 4 years to adult.[14,23] Some investigators concluded that the increase in dental arch width is only about one-fourth of the increase in midline sutural growth at the level of the first molars after the age 10 years.[14]

Melson's study using tissue blocks from autopsy material described the changes in the midpalatal suture morphology that occurs with age. At birth, the suture is broad and slightly sinuous, but at the age of 10 years, it develops into the typical squamous suture where the palatine part overlaps the maxillary portion. Incipient interdigitation can be seen in the lower, broadest portion of the suture at 10 years old. After 13 to 14 years of age, the suture shortens and becomes wavier thus narrowing the connective tissue sheet that connects the lateral parts of the palate. Melson found that, after the age of 15 years in females and 17 years in males, the sutures consist of a narrow sheet of connective tissue with inactive osteoblasts. With this knowledge, she proposed three stages of post-natal development of the palatal suture: the infantile period, the juvenile period, and the adolescent period. During the first stage, the suture is broad and Y-shaped, with the vomer bone in a V-shaped groove between the two halves of the maxilla. The juvenile period is characterized by a wavy sutural structure, while the third and final adolescent period shows signs of increasing interdigitation.[24]

Etiology of Maxillary Constriction

Maxillary constriction is defined as maxillary width that is narrower than the norm for a particular age group. A recent U.S. Public Health Survey concluded that the prevalence of maxillary constriction is 9.4% of the general population with little change from 8-50 years of age.[26] There is no significant differences in prevalence between race-ethnicity groups and sexes.[26] The causes of maxillary width discrepancies could be genetic, environmental, or a combination of both factors. In patients with craniofacial syndromes such as Velocardiofacial Syndrome, the etiology is inherited. Though the gene responsible has not been identified, it has been ascertained that a small part of chromosome 22, known as 22q11, is missing in the vast majority of these individuals (82%) who are diagnosed as having VCFS.[27] More specifically, the clefting of the palate associated with this syndrome is the direct cause of the maxillary constriction.

In other cases, however, maxillary constriction is thought to be environmental, as seen with patients who have an abnormal function of the orofacial complex. Studies by Harvold, Cheirici, and Vargervik[28] showed that alterations in respiration can cause posterior crossbites to develop. In this study, they blocked the nasal airways of rhesus monkeys forcing the animals to convert from nasal to obligate mouth breathers. This change in respiration pattern led to three observations: a lower tongue posture, lowering of the mandible, and less transverse development of the maxilla.[28,29]

Other authors conclude that the etiology is multifactorial. Although the author's specific explanation are not offered, it is stated that the maxillary skeletal base, dentoalveolar processes, and function play a role in the development of the transverse discrepancy.[8,13,26,29]

Skeletal Effects of Rapid Maxillary Expansion

Rapid maxillary expansion occurs when the forces applied to the teeth and alveolar processes exceed the limits of orthodontic tooth movement. This applied pressure acts as an orthopedic force which opens the midpalatal suture.[29] Activation of the appliance causes immediate compression of the periodontal ligament, followed by bending of the alveolar process, and tipping of the anchor teeth, resulting in a distraction force on the midpalatal suture.[6] In ideal circumstances, the midpalatal suture disarticulates with minimal forces. It has been shown that as expansion forces accumulate during the first month of treatment, the mineral content within the suture decreases.[29] Ekström found that the mineral content within the suture increased rapidly in the first month following expansion and returned to its initial level within three months.[30]

The force levels distributed to the maxillary complex as a result of RME can vary greatly. In a recent study by Chaconas,[30] he found that the force levels were appliance dependant such that each produced distinct load-activation characteristics. A single activation of a Haas or Hyrax appliance produces 3-10 lbs of force with a rapid initial decay followed by slower decay curve.[30] It was also estimated that 16.6–34.8 lbs of force is the maximum load expressed in a given patient (Figure 1).

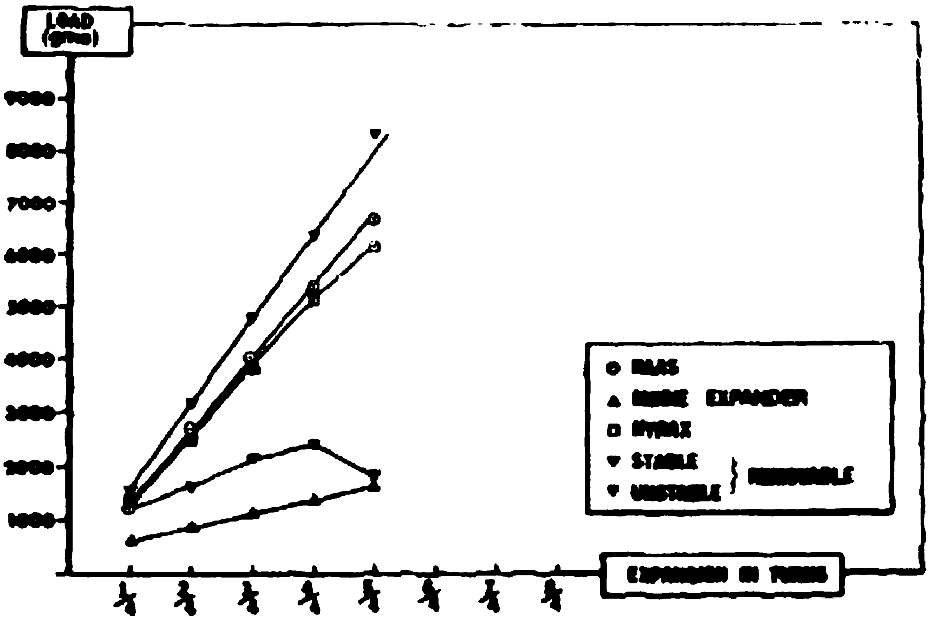

Figure 1: Force-activation curve for jackscrew and Minne-expander appliances[30]

Using photoelastic visualization, Chaconas concluded that the major resistance to the expansion forces was not in the midpalatal suture but other maxillary articulations such as the zygomatic and sphenoidal sutures. Additional stresses generated by rapid maxillary expansion were concentrated at the anterior portion of the palate and radiate superiorly along the perpendicular plates of palatine, lacrimal bone, nasal bone, zygomatic bones, and finally the pterygoid plates of the sphenoid.[30] Given these findings, Chaconas stated,

> Intermaxillary expansion will be difficult to obtain in the case of adults where the maxilla is fused to these structures, regardless of how much the suture between the two halves of the maxilla is affected by the orthopedic forces. This should indicate to the clinician that these orthopedic devices should be used sparingly and judiciously, and with an understanding of what deep anatomic structures are actually being affected by incremental activation of these appliances. In other words, the clinician should realize that, with each activation of these appliances, he or she is producing not only an expansion force at the intermaxillary suture but also forces on other structures within the craniofacial complex which may or may not be beneficial for the patient.[30]

Wertz showed that the anterior-posterior separation of the palate seen with RME occurs in a non-parallel fashion.[11] Using three dry skulls, greater expansion was noted in the anterior portion than the posterior. Non-parallel expansion was also seen in the maxillary suture in the superior-inferior direction, such that more expansion was seen inferior at the level of the dentition in comparison to the skeletal components of the maxilla and nasal floor. Furthermore, it was noted that, as the maxillae separate, the alveolar plates tip and bend buccally, in addition to tipping and translation of the teeth.[12]

In addition to the skeletal effects of rapid maxillary expansion stated above, previous studies by Haas and Wertz showed that the maxilla is displaced downward and forward.[6,12] The amount and degree of movement is related to its original position. Fifty percent of the cases returned to the original position in the post-expansion period.[5-7,12] Lateral bending of the alveolar processes has been noted by multiple authors.[5-8,10,12,29,31] Relapse of lateral bending is thought to be due to residual forces remaining after initial expansion.[31] Rapid maxillary expansion is also associated with down and backward rotation of the mandible due to the change in the position of the maxilla, extrusion of maxillary teeth, and bending of the alveolous.[6-8,12,29,31,32] The magnitude and permanency of change of the maxilla is not agreed upon in the literature.

Dental Effects of Rapid Maxillary Expansion

The greatest changes as a result of RME occur in the dentition; however, the degree and direction is variable among studies. Haas noted a decrease in the sella-nasion to upper incisor angle in 76% of his cases in the post expansion period.[6]

The dental effects of RME supersede the skeletal changes because the appliance is anchored to the teeth. The diastema observed between the central incisors is a hallmark sign of "successful" RME, indicating that the mid-palatal suture has split. Haas estimated the diastema width to be half the amount of screw activation of the appliance, while Lagravere reported an average width of 2.98 mm.[6,33] Following expansion, mesial tipping of the incisors occurred, and the investigator postulated that this was due to elastic recoil of the transeptal fibers. Unaided return of proximal contact and uprighting of the central incisors occurs in about 4 months.[11,12] Haas postulated that the "circumoral musculature" was responsible for the closure of the diastema and decreased the post-expansion arch perimeter, but had no clinical evidence.[6,7]

Powerful lateral forces are exerted against the tooth roots, periodontal membrane, and marginal alveolar bone during RME treatment causing the teeth to tip and translate through alveolar bone. The maxillary molar angulation changes 1-24° depending on the study design and treatment protocol.[6,7,32] One meta- analysis reported an overall average of 3° of tipping of all the posterior teeth and stated that this change is not clinically significant.[33] The transverse changes observed at the level of the dentition vary depending on the report and amount of expansion desired. However, several meta-analyses show that the intermolar width increases from 6.0 to 6.75 mm and the intercanine width increases 5.0-5.3 mm. In addition, the maxillary molars extrude 0.5-mm, and the overjet increases an average of 1.3 mm.[33]

Greenbaum stated that, "Iatrogenic damage as following these excessive forces should not be expected."[34] His study compared the periodontal effects of RME with varying appliance designs versus controls, and concluded that there was no significant difference among the groups.[34] Garib *et al.*[35] reported contrasting results to Greenbaum's study, in that they found reduced buccal plate thickness of the anchor teeth ranging from 0.6-0.9 mm. They reported significantly increased lingual plate thickness in Hyrax treated patients. Most significantly, however, was that the Hyrax treatment group had a number of anchor teeth with dehiscence of the buccal plate.[32,35] Additionally, Barber[36] and Lanford[37] reported marked buccal root resorption of anchor teeth, while the non-anchor teeth were not affected. Fortunately, significant root repair post-expansion was reported on most of the teeth.[36,37]

Finally, one of the most important changes seen in the dentition is a change in the total arch perimeter. Adkins[1] reported that changes in premolar width are highly predictive of changes in arch perimeter. It has been stated that the average increase in arch perimeter is equal to seventy percent of the transverse expansion at the premolars.[1] Geran reported an average of 4 mm increase in arch perimeter in patients who underwent RME.[3]

Timing of Treatment

Angell designed the expansion appliance to take advantage of the patency of the midpalatal suture and aid in normal development of the maxillary complex.[2] Such transverse development is facilitated via separation of the two maxillary segments using the dentition as anchorage points. Thus, it is important to treat patients with maxillary constriction prior to the fusion of these facial sutures. Most researchers agree that growth in the median suture of the maxilla ceases at an average age of 16 years in females and 18 years in males with much individual variation.[15,18,21,23,24,29] Using autopsy material, Thilander found fused sutures in 15 year old cadavers while there were unfused sutures in 25 year old cadavers. Overall, rapid maxillary expansion should be done prior to the peak growth velocity in order to induce more skeletal transverse changes.[38] The average peak growth velocity occurs at 7-11 years in males and 6-11 years in females.[18] In addition, the age related decrease in bone regeneration within the sutures in older patients further suggests that earlier expansion is advantageous.[39]

There are many sutures involved in RME besides the midpalatal suture. It is essential that the fusion times of these sutures be well understood. Unfortunately, there is no scientific evidence regarding the fusion of the sutures surrounding the perpendicular plates of the palatine bone, zygomatic, nasal, pterygoid, and lacrimal bones.

Rapid maxillary expansion can be achieved in older patients, however the orthopedic changes are relatively small.[11] This is due to the fact that one or more of the sutures may be fused causing greater resistance to the skeletal changes and a greater tendency towards dental changes. Some researchers have stated that RME is possible in older patients but may involve fracturing of the fused sutures. In addition, the tendency towards relapse is 50% greater in older patients.[11]

The Hyrax Appliance

Since Angell's first appliance, there have been many efforts to modify and improve RME. Haas first introduced his appliance in 1958.[5] It is a fixed appliance with bands on the first premolars and molars, connected to a jackscrew at the center of the appliance with acrylic coverage against the palate. Although it has been stated that the tissue-borne Haas appliance applies more parallel expansion force to the alveolar ridges, the potential for tissue irritation is great with this appliance.[6]

William Biederman developed an alternative appliance in 1968.[40] It was first called the Biederman or Hygienic appliance due to its all wire frame soldered to seamless bands. Biederman claimed that this hygienic rapid expander (Hyrax) decreased irritation to the palatal mucosa while at the same time making it easier to fabricate and minimized the effects on speech.[40]

Recent studies comparing the traditional Haas and Hyrax appliances have shown a variety of results. Garib *et al.* stated that there were no significant differences between the two appliances.[32,41,42] Asanza reported similar dentofacial effects, but the Hass had a statistically greater increase in the vertical dimension.[43] In contrast, Olivera found that the Haas demonstrated greater orthopedic movement, and the Hyrax had an increased mean palatal angulation.[41]

Assessment of Rapid Maxillary Expansion

Cephalometric analysis is widely used in orthodontics and, until recently, has been the standard of imaging for treatment planning and analyzing treatment results. This method provides a static visualization of both the hard and soft tissues of the head and neck and permits measurements to be performed. Advantages of using a full head lateral radiographs for measurements include low cost, low radiation, is easily accessible, however, there are fundamental problems. It is difficult to standardize patient positioning, technique, and magnification. In addition, a differential projection enlargement results from the distances among the x-ray source, the subject, and the film. This inaccuracy is due to several factors. First, there is generalized enlargement of the image as a whole, varying from 10-15%.[44] One side of the patient is closer to the x-ray beam resulting in the side closest to the source being magnified to a greater degree.[45] Finally, a radiograph is a two-dimensional representation of a three-dimensional object, which means anatomical structures overlap and measurements are not real.[46]

When examining the nasomaxillary complex on a cephalometric radiograph, qualitative information and basic measurements can be obtained. However, transverse measurements and form can be altered by something as simple as the head posture of the patient. Since the images are magnified and distorted with respect to the original form, it is logical to assume that the measurements obtained from these images will be inaccurate. Adams[46] stated that these discrepancies imply that the measurements taken from a cephalometric radiograph do not represent anatomically accurate data and anatomical relationships.[46]

Magnetic resonance imaging (MRI) provides a radiation-free means of imaging the nasomaxillary complex. Although this method provides a clear visualization of both the hard and soft tissues, the added expense, limited availability, and limitations with metallic appliances make it difficult to use for the purpose of this investigation.

Traditional computed tomography (CT) is similar to MRI in that it provides a three-dimensional visualization of skeletal structures. However, soft tissue structures, such as the soft palate, are difficult to differentiate on CT. The high radiation and cost associated with spiral and helical CT scans also make them less desirable. Traditional CT imaging generates a continuous, flat, fan-shaped beam of photons which are directed perpendicular to the long axis of the subject. Both the source and sensor move around the subject at the same rate at approximately 1 mm increments, providing multiple projections of the subject at a known geometry. The individual projections are then compiled to reconstruct volumetric images using mathematical formulas. These newly generated images can then be used to obtain qualitative observations and quantitative measurements.[47]

Several disadvantages of traditional CT imaging are evident. The process can be time-consuming because each trans-axial slice is captured separately. Additionally, any movement of the patient during the imaging process can lead to a distorted reconstruction of the image. Finally, the radiation exposure to the patient is very high due to the extended time needed to complete a tomographic scan.

Cone beam computed tomography (CBCT) has offered many solutions to the shortcomings of traditional CT. The cone shaped beam allows for shorter imaging times and lower radiation exposure.[48] Scan times average 10 seconds using the Hitachi CB MercuRay™ CBCT scanner (Hitachi Medical Corporation, Tokyo, Japan) decreasing the likelihood of distortion with the radiation exposure similar to the range of a standard dental radiograph series.[48-50] The spatial resolution is equivalent to the resolution of a standard spiral CT but at a significantly lower radiation dosage. The effective dose of a CBCT is 200-400 μSv versus a spiral CT at 2000 μSv.[51]

The Hitachi CB MercuRay™ CBCT scanner used in this study is a 12-bit grey scale system that provides greater contrast and resolution compared to other 8-bit CBCT machines. The 9 inch field of view offered by the Hitachi CB MercuRay™ CBCT scanner allows for increased focus on the nasomaxillary complex. The upright scanning position used with this machine is also an advantage in that it allows for the patient to be in their natural head position.

The accuracy of measurements obtained from computed tomographic images have been investigated by several authors. Cavalcanti concluded that the measurements were very accurate when compared to physical measurements of dry skulls.[47] He reported measurement error ranging from 0.45-1.44%. Kobayashi *et al.* completed a similar study and found a measurement error of 1.4% and concluded that this was within a clinically tolerable range. Stratemann reported highly accurate measurements in all dimensions ranging from 0.09-0.30%.[52] These studies have confirmed that the measurements obtained from reconstructed CBCT images are anatomically accurate.

Until recently, rapid maxillary expansion has been analyzed using two-dimensional cephalograms and/or study models. Measurements were made using dental and bony landmarks, and each author developed their own analyses. Haas created one of the first analyses based on 45 patients with maxillary or nasal deficiency.[6] Using serial PA cephalograms superimposed on each other, parallel vertical tangents were constructed to the greatest convexity on the lateral walls of the nasal aperture, second or third molars, and the central incisors. Linear measurements were then taken across each between each pair of tangents (Figure 2).

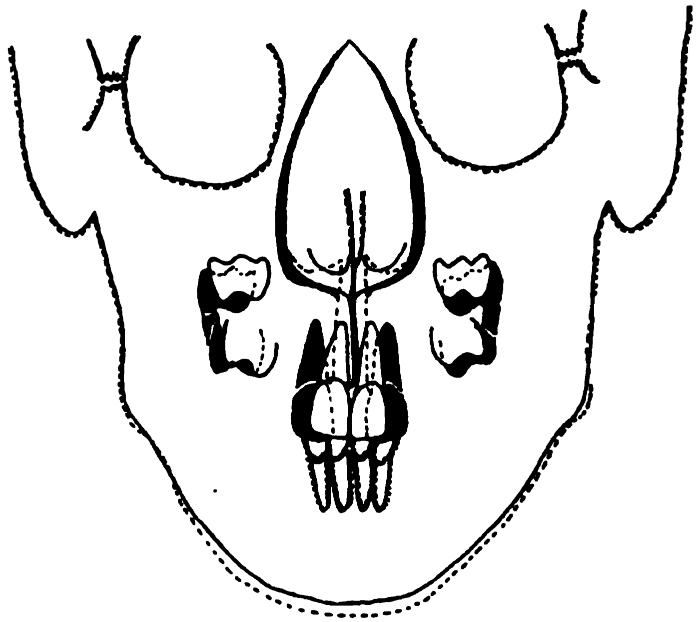

Figure 2: Serial PA cephalograms superimposition demonstrating maxillary expansion[6]

A common method used to measure maxillary expansion came from the work of Baccetti and McNamara.[38,53] This analysis identifies skeletal and dental landmarks on PA cephalograms. Following landmark identification, linear measurements are taken by connecting the bilateral landmarks (Figures 3, 4).

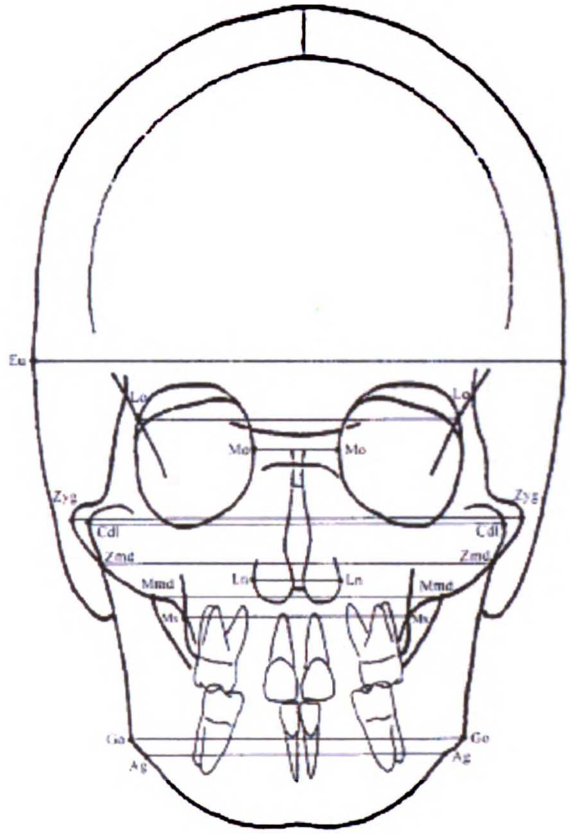

Figure 3: Cephalometric landmarks used by Baccetti and McNamara[38,53]

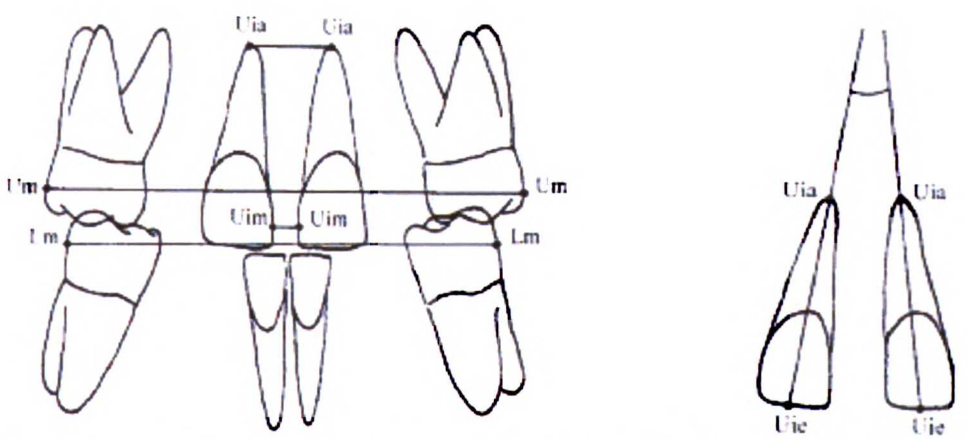

Figure 4: Dental measurements on posteroanterior film used by Baccetti and McNamara[38,53]

Unfortunately, this analysis only measures the two dimensional changes, and results can be skewed by the magnification, superimposition of overlying structures, and head posture of the patient in the cephalostat.

Later work by the Geran *et al.* added measurements taken on dental casts to the original methods by Baccetti and McNamara.[53] They used the casts to measure dental changes in arch width, arch depth, molar angulation, and arch perimeter (Figure 5).

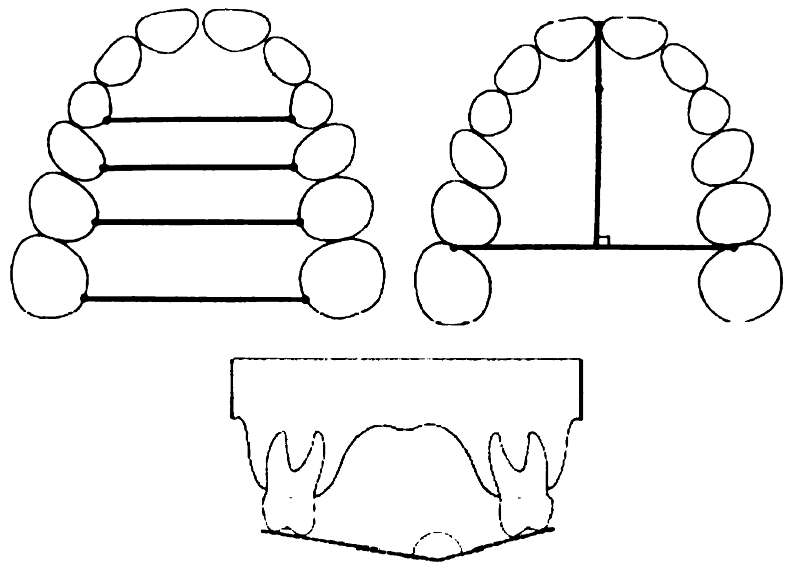

Figure 5: Cast Measurements used by Geran[53]

The addition of dental measurements to RME analysis was very important to understanding rapid maxillary expansion because the appliance is anchored to the dentition. Traditional radiographic evidence of the dental effects of RME is difficult to measure due to the superimposition of other structures on the dentition. However, this cast analysis method is not without its disadvantages. Defining the true angulation of the teeth is difficult without complete visualization of the roots of the teeth. Additionally, the measurements from the casts may be distorted depending on the materials and method used to construct the models.

To eliminate the disadvantages mentioned above, Garib *et al.* used three dimensional imaging with a spiral CT system to analyze the effects of RME.[32,35] With this method, distortion and superimposition of landmarks was eliminated. They used coronal slices of the maxilla to measure the transverse changes at different levels of the maxilla (Figure 6).

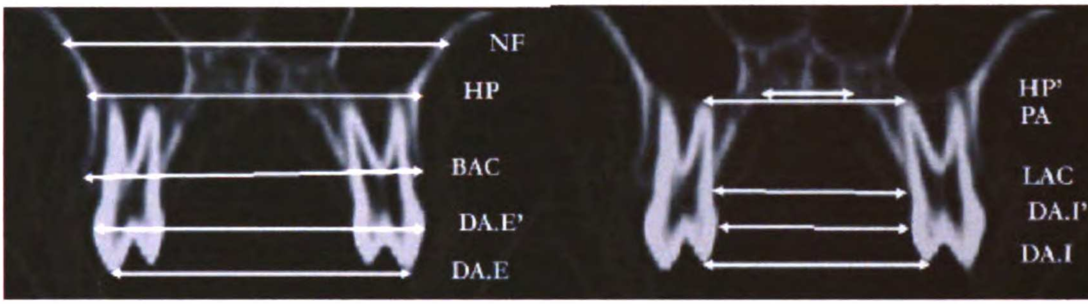

Figure 6: Transverse measurements of the maxilla used by Garib et al[32,35]

Garib also measured the changes in inclination of the dentition by drawing a line through the palatal cusp tip and root apex, and one line perpendicular to the lower border of the CT image (Figure 7).[32,35]

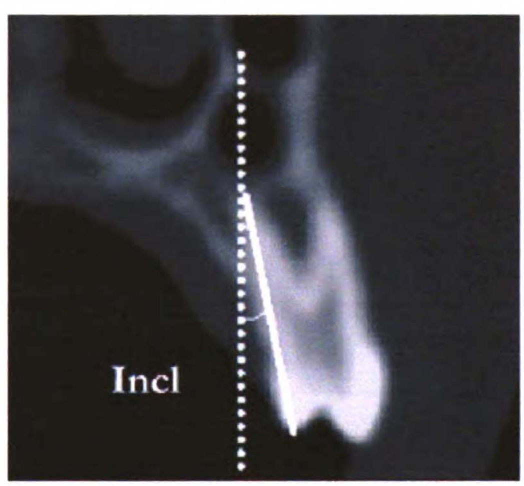

Figure 7: Determination of tooth inclination[32,35]

This method allows for complete visualization of the crown and root of the tooth decreasing the likelihood of error. However, constructing the line from cusp tip to root apex may be difficult to repeat consistently due to changes in the position of the teeth from the time point one to time point two. The same is true for the construction of the perpendicular line. This is due to the fact that all three planes of the scan can be manipulated using the CT software making the perpendicular line arbitrary.

Materials & Methods

Patient Selection

This study was a prospective longitudinal study approved by the University of California, San Francisco Committee on Human Research (# H893-23246). Fourteen consecutive patients (7 Male, 7 Female) were recruited from the UCSF Orthodontic Clinic based on the following selection criteria:

Inclusion Criteria:

1. Skeletal transverse discrepancy with need for rapid maxillary expansion (RME) judged by an experienced orthodontist
2. Need for treatment with full fixed appliances (FFA) during the 6 month retention period
3. All ages in which rapid maxillary expansion was feasible as judged clinically using radiographs and medical history
4. Complete set of images at desired time points
5. Informed consent obtained

Exclusion Criteria:

1. Patients with craniofacial anomalies that could alter the effects of RME
2. Patients undergoing orthognathic surgical intervention, such as a surgically assisted rapid maxillary expansion (SARPE)
3. Orthodontic appliances present prior to the start of treatment with RME
4. Lack of compliance in obtaining the required images and/or expansion protocol

Enrollment in the study was open for 15 months. Initially, sixteen patients were recruited for the study. Two of the patients were lost to follow-up. The remaining patients had a mean age at the time of the first imaging appointment of 14.8 ± 1.0 (13.1-16.4 years). A summary of patients involved in the study can be found in Table 1.

Table 1: Data on patient age and gender

Patient #	Gender	Age at time of 1st imaging (years)
1	Female	13.6
2	Female	15.6
3	Male	15.7
4	Male	16.4
5	Female	14.1
6	Female	14.6
7	Female	15.2
8	Female	13.1
9	Female	13.6
10	Male	16.0
11	Male	14.6
12	Male	14.6
13	Male	13.0
14	Female	12.8

Each patient was treated with a tooth–borne hygienic rapid expander (Hyrax). The expander consisted of an 8, 11, or 13 mm Dentaurum expansion screw (Dentaurum, Ispringen, Germany) with four 0.051-in stainless steel arms soldered to bands on the first maxillary premolars and first molars. A 0.036-in stainless steel supporting wire was placed lingual to dentition and bands to increase rigidity of the appliance and extend the force of the expander to the canines and second molars if they were present (Figure 8).

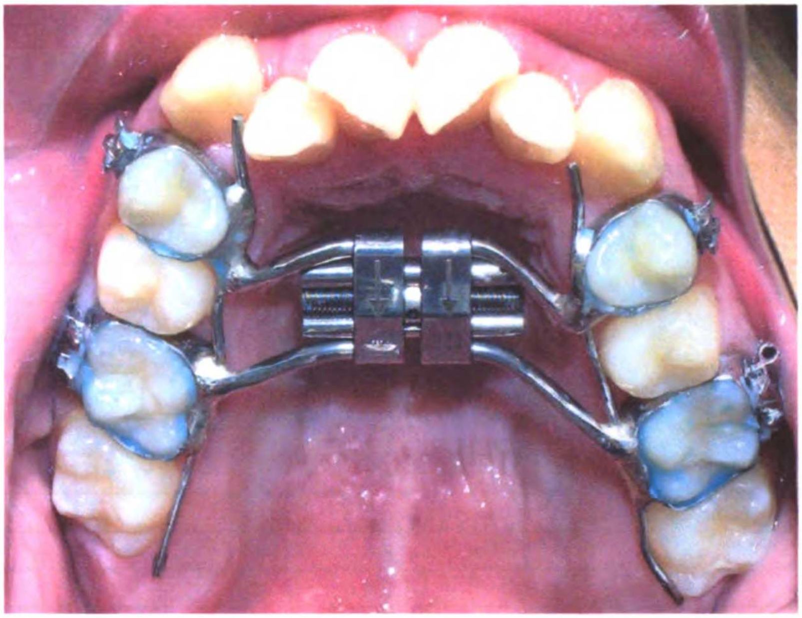

Figure 8: Hyrax expander in a 15.2 year old male patient

The expander was activated one quarter turn of the expansion screw (0.2mm) at the time of delivery, followed by one quarter turn each day. Activation continued until the transverse discrepancy was overcorrected such that the palatal cusps of the upper molars were in edge-to-edge contact with the buccal cusps of the mandibular teeth. The jackscrew was immobilized at this stage, and the RPE was kept in place for at least 3 more months. Upon completion of the active expansion phase of treatment, each patient was orthodontically treated with full fixed appliances. If the expander was removed prior to the completion of the 6-month retention phase, expansion was retained with an upper lingual arch or transpalatal arch (Table 2).

Table 2: Expansion duration & retention method

Patient #	Duration of Expansion (days)	Method of Retention
1	56	Lingual Arch
2	50	Lingual Arch
3	39	Lingual Arch
4	68	TPA
5	91	TPA
6	60	Hyrax
7	65	TPA
8	65	Hyrax
9	70	Lingual Arch
10	44	Lingual Arch
11	66	Lingual Arch
12	58	TPA
13	82	TPA
14	72	Hyrax
	Mean 63.3 ±13.9	

Cone beam computed tomography (CBCT) scans were taken at the UCSF Division of Orthodontics 3-D Craniofacial Imaging Center using the Hitachi CB MercuRay (Hitachi Medical Corporation, Tokyo, Japan) cone-beam CT scanner. All scans were taken by the same technician using the 9-inch field of view at the manufacturer's recommended settings of 15mA and 120kVp. Patients were positioned with their head stabilized in the headrest to prevent unwanted movement during the 10-second scan, teeth together in centric occlusion, and the Frankfort Horizontal plane parallel to the floor. Patients were instructed to sit still, breathe through their nose, and place their tongue on the roof of the mouth.

Each patient was scanned at three different time points: T0, T1, and T2. The first image (T0) was obtained prior to the delivery of the expander (variation of time between initial records to the day of delivery of the appliance was 1-36 days) which represented the subject's baseline condition prior to expansion. The second time point (T1) was taken at the completion of the active expansion as stated above. This stage represented the dental and orthopedic changes as an immediate result of the active expansion without relapse or alignment with fixed appliances. The third and final time point (T2) image was taken six months after completion of active expansion. This time point was chosen because Bishara[29] stated that the majority of the healing of the suture has occurred within three months of the last activation. Isaacson also showed that the forces that cause lateral bending of the alveolus are completely dissipated within 5-6 weeks of expansion.[10,29] Most importantly, this 6 month time frame allowed for the full-fixed appliances placed in the post-expansion period to have an effect on the dentition. All of the T2 images were taken 5½ -7 months after active expansion.

To date, a number of methods exist for studying the effects of rapid maxillary expansion.[6,32,35,38,43,53] However, there is no consensus on one approach in the literature. Furthermore, little work has been done using distortion-free three dimensional images to quantify the skeletal and dental effects of RME. We chose to create an analysis based on the studies by Garib *et al.*[32,35] Our analysis measured similar changes of RME with the consistent landmark identification using the Accurex 2.1 software (CyberMed Inc., Seoul, Korea) to generate two and three dimensional images.

Determining the amount of skeletal and dental expansion

First, each of the scans were randomly assigned a number and loaded into a database such that each scan was analyzed without the operator identifying the patient or time point. Two dimensional coronal images were created perpendicular to the midsagittal plane in order to measure the amount of skeletal and dental expansion. This was done in the MPR mode of the Accurex 2.1 software that allows a view of the area of interest in any vantage point including the coronal, sagittal, and axial planes. A coronal section through the three dimensional midpoint of the right and left first premolars was created (Figure 9).

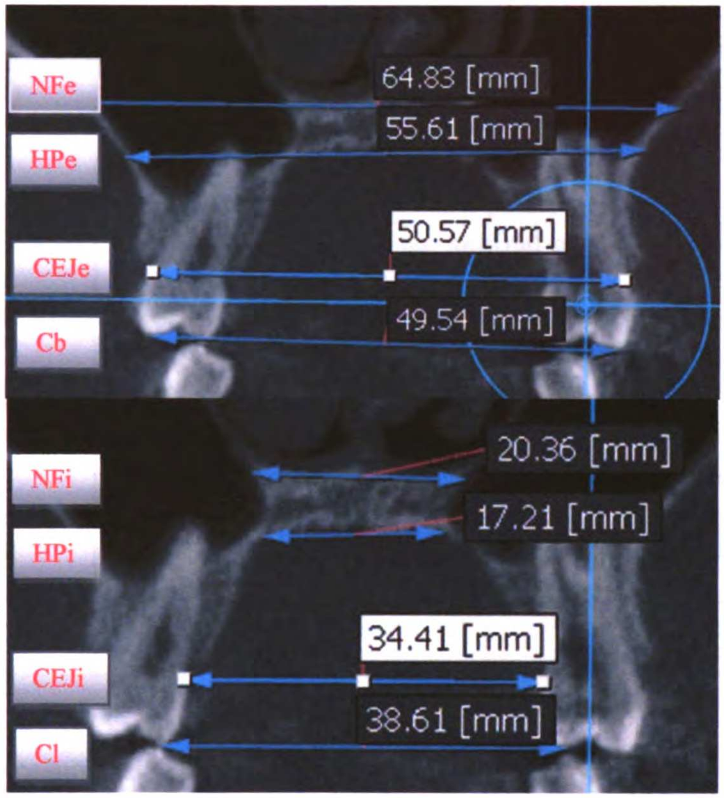

Figure 9: Transverse Measurements: Top: external measurements Bottom: Internal measurements. Abbreviations in Table 3

The following measurements were taken at each of the three time points described above (Table 3).

Table 3: Linear measures used to determine the amount of skeletal and dental expansion

Linear Measures	Description
Nasal Floor (NF)	Maxillary width tangent to the nasal floor at the most inferior level
Hard Palate External (HPe)	Maxillary width from the external points of the buccal plate at the level tangent to the hard palate
Internal hard Palate (HPi)	Maxillary width from the internal points of the hard palate
Cementoenamel Junction Exterior (CEJe)	Width of the dental arch at the level of the buccal CEJ of the right premolar/molar to the buccal CEJ of the left premolar/molar
Cementoenamel Junction Interior (CEJi)	Width of the dental arch at the level of the lingual CEJ of the right premolar/molar to the lingual CEJ of the left premolar/molar
Buccal Cusp Tip (Cb)	Dental arch width at the level of the buccal cusp tips
Lingual Cusp Tip (Cl)	Dental arch width at the level of the lingual cusp tips

Similar measurements were then taken using coronal sections through the three dimensional midpoint of the second premolar and first molar, respectively, for each of the three time points. The values in millimeters (mm) were entered into Excel software (Microsoft, Redmond, WA). The data was then analyzed statistically using SAS 9.1 Statistical Software (SAS, Cary, NC). Changes in measurements between the timepoints were analyzed using two-tailed t-tests with a level of significance of $p<0.05$.

Determination of changes in axial inclinations of the teeth

Similar two dimensional coronal sections described above were used to measure the axial inclinations of the premolars and first molar. Each slice was printed and assigned a random number. The scans were analyzed in numerical order in order to blind the operator from the subject's identity. The inclination of each tooth with respect to the midline structures was measured by hand using acetate paper and pencil.

First, the orbits, zygomas, maxilla, and nasal structures were traced in order to facilitate superimposition of later timepoints. Second, a horizontal axis of each section was established by construction of a line tangent to the right and left superior orbital rim of each patient. When the superior orbital rim was not included in the nine-inch scan, a line tangent to crista galli was used. Third, a best fit midsagittal line was constructed perpendicular to the horizontal axis through crista galli and the nasal septum. The axis of each tooth was established by creating a line perpendicular to the occlusal surface of each tooth. The relationship of each tooth to the midsagittal line was measured in degrees (◦) using a cephalometric protractor and entered in an Excel spreadsheet (Microsoft Corporation, Redman, WA).

All three timepoints were measured in the same manner. Statistical analysis was done using paired t-tests in a similar manner as stated above (Figure 10).

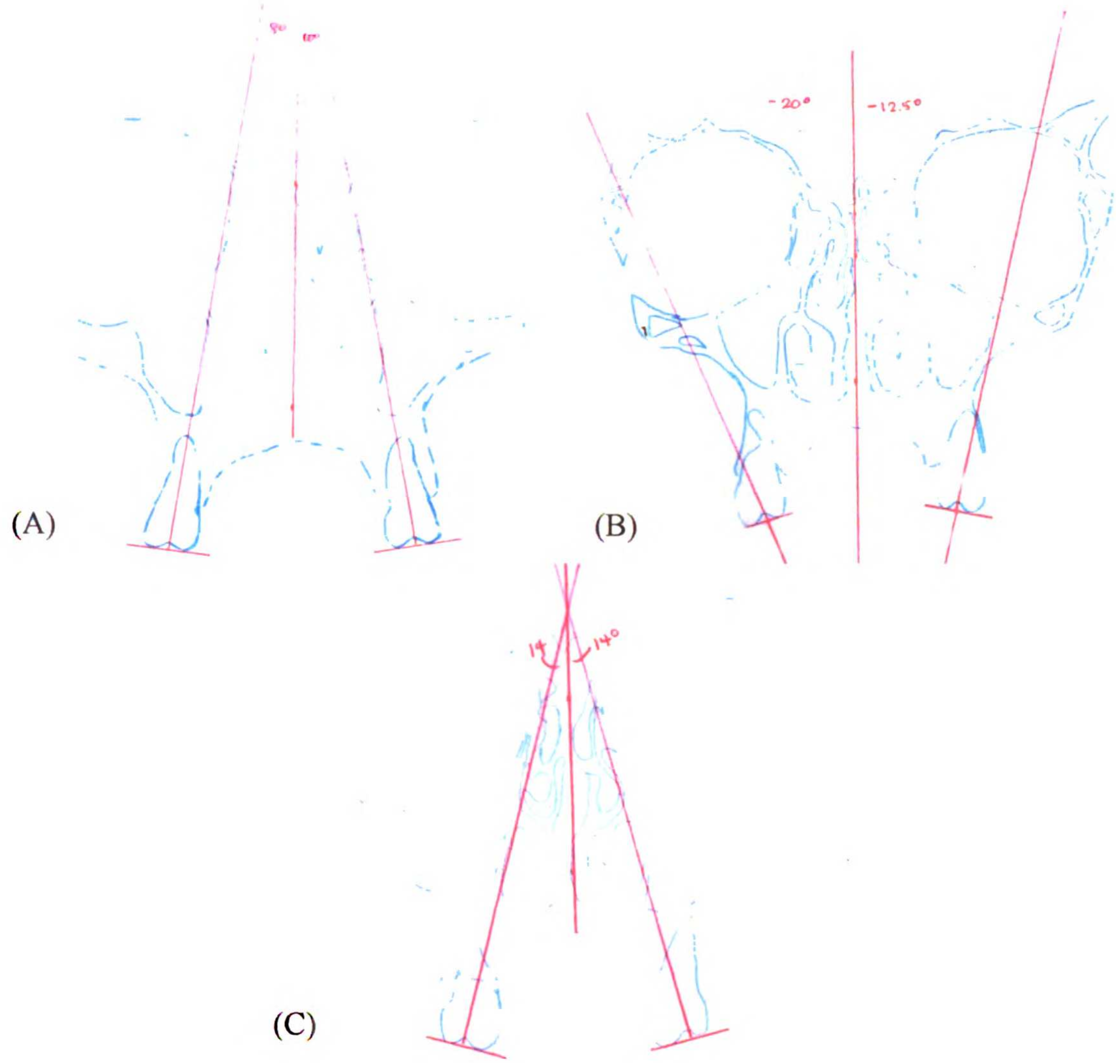

Figure 10: Individual tracings of (A) 1st premolar, (B) 2nd premolar, and (C) 1st molar in the coronal view

Once the measurements were completed, all three scans were then superimposed using a best fit method. Crista galli and the mid-sagittal structures were the primary landmarks for superimposition. All skeletal and dental structures were traced by hand on acetate paper with different colors corresponding to each time point to show the skeletal and dental changes among the scans (Figure 11).

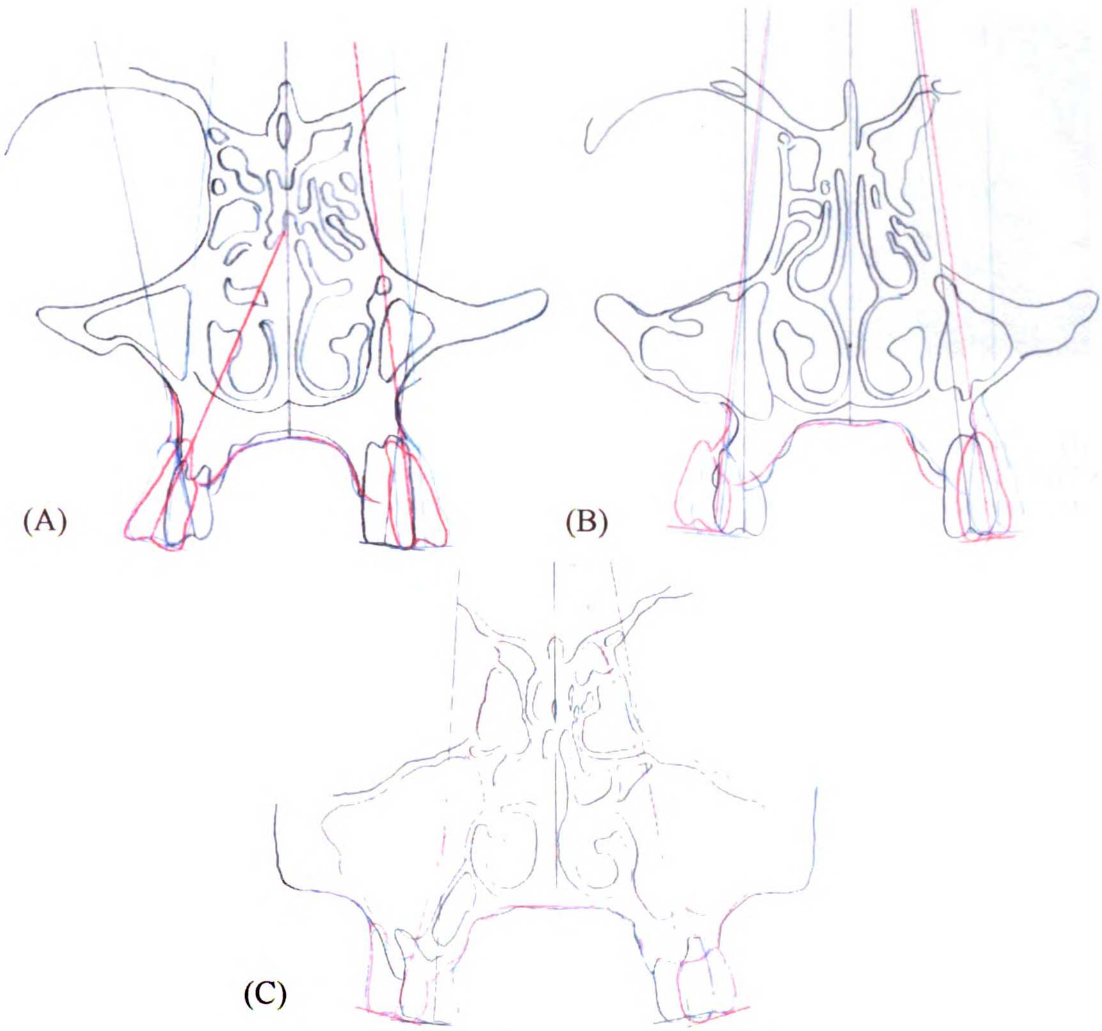

Figure 11: Superimpositions of (A) 1st premolar, (B) 2nd premolar and (C) 1st molar in the coronal view

Determination of Patency of Midpalatal Suture

Qualitative evaluation of the changes in the midpalatal suture was completed by segmenting the three dimensional image of the maxilla using the sculpting function of the Accurex 2.1 software for each timepoint. The orbits, mandibular structures, and scatter radiation were removed one slice at a time to allow clear visualization of the palate and maxillary teeth (Figure 12).

A. B. C.

Figure 12: Qualitative evaluation of patency of the midpalatal suture from segmented volumetric images using Accurex software from a Hitachi MercuRay CBCT scan. (A.) Maxilla pre-treatment (T0) (B). Maxilla post-expansion (T1) (C). Maxilla 6-months post-expansion (T2)

Although qualitative evaluation of the suture provides great information, it was also necessary to attempt to quantify the changes in the suture as well. Two-dimensional coronal slices through the three-dimensional center of the canines and molars were created using the Accurex 2.1 software. Using the histogram tool in the MPR mode, a line was drawn through the middle of the palate from left to right. A histogram of the Hounsfield Units (HU) within the suture was then generated. The results of all three scans were then superimposed using Photoshop CS2 9.0 software (Adobe Systems Incorporated, San Jose, CA, USA: Figure 13).

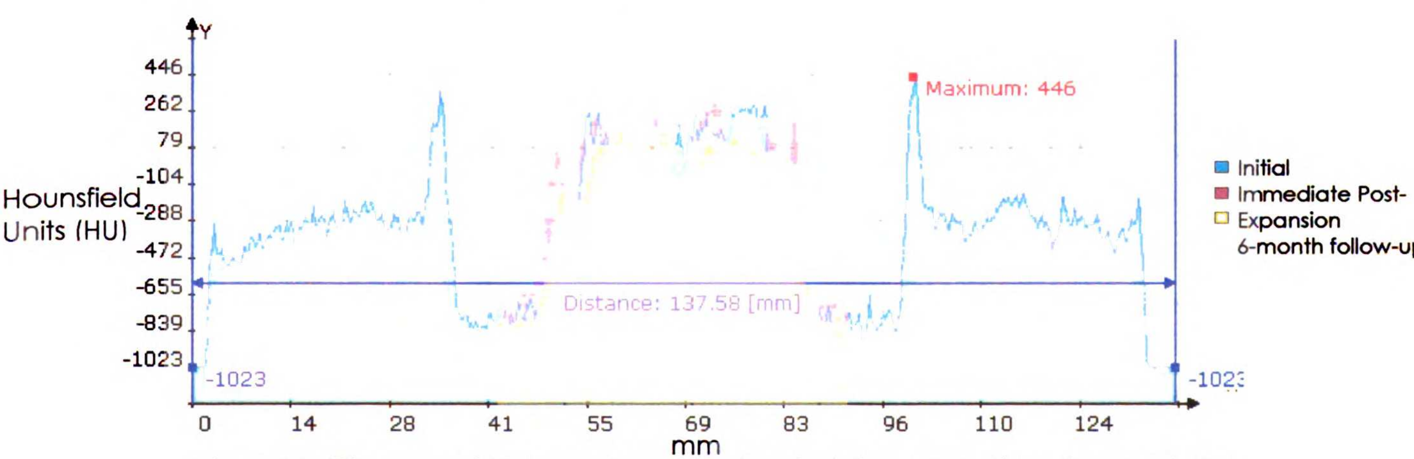

Figure 13: Histogram of 15.2 year old male patient depicting a single line axis through the palate at each of the time points when visualized in the coronal slice view

Intra-rater Variability

Intra-operator variability was assessed by creating new coronal sections of each timepoint from three subjects using the Accurex 2.1 software. Once complete, each of the images was measured in the same manner as mentioned above to determine the amount of transverse expansion, change in inclination of the teeth, midpalatal suture, and surrounding structures. This procedure was repeated a total of three times for each subject, each 1-week apart. The variability for each of the measurements was quantified using a Lin's concordance regression analysis.

Statistical Analysis

Initial regression analyses were completed to determine if there was any correlation between the results of expansion and age. Similar comparisons were then used to determine if the results of expansion were correlated with the age of the subjects. This allowed for appropriate pooling of the data for further analysis. Intermediate and final transverse measurements of the maxilla were compared to the original controls using paired, two-tailed t-tests. This comparison determined if there were significant changes in the dimensions of the maxilla as a result of RME.

The changes in transverse dimensions at various coronal landmarks (ie. 1stpremolar, 2nd premolar, and 1st molar) were compared with each other to determine if there were any statistical differences between the results using separate paired, two-tailed t-tests.

Relationships of the teeth to the mid-sagittal line were compared to the original control record using paired, two-tailed t-tests. These statistics were used to determine if there was any difference in the change in angulation resulting from RME. Paired, two

Results

Intra-rater Reliability

The reliability of all of the landmarks were acceptable with a strength of agreement of "almost perfect" except for the internal and external nasal floor landmarks. The nasal floor landmarks were considered "poor" (Table 4).

Table 4. Intra-rater reliability using Lin's Concordance

Variable	Concordance Correlation Coefficient (ρ_c)
External Nasal Floor (NFe)	.829
Internal Nasal Floor (NFi)	.896
External Palate (Palate e)	.992
Internal Palate (Palate i)	.999
External Cementoenamel Junction (CEJe)	.999
Internal Cementoenamel Junction (CEJi)	.993
Buccal Cusp (Cuspb)	.991
Lingual Cusp (Cuspl)	.996

Concordance Correlation Coefficient Key:

(<.90)	Poor
(0.90–0.95)	Fair
(0.95–0.99)	Substantial
(>0.99)	Almost perfect

Comparing maxillary transverse dimensions at different time points

Data gathered from all subjects at three time points showed no statistical differences in the amount of skeletal and dental expansion between the males and females in the study. No significant difference was found among the age groups as well, therefore, all of the subjects were grouped together for further comparison (t-test $p>0.05$). The poor inter-rater reliability with respect to the nasal floor measurements was considered when evaluating changes among the time points.

At the level of the first premolar, there was a significant increase in all dimensions from the initial pre-treatment time point (T0) to immediate post-expansion time point (T1) except at level of the external nasal floor ($p = 0.001$-0.0028; Table 5). No significant changes were seen from the immediate post-expansion time point (T1) to the 6-month post-expansion follow-up (T2). The second premolar transverse measurements increased significantly from T0 to T1 for all landmarks except the external nasal floor and external palate ($p < 0.001$). No significant changes were seen from immediate post-expansion to 6-months post-expansion. The changes in transverse dimensions at the level of the first molar were similar to those seen in the other teeth. There was a significant increase in all dimensions from T0-T1 except for the external nasal floor ($p = 0.0032$-0.001) and insignificant changes from T1-T2 ($p = .0917$-0.8628).

Table 5: Change in maxillary transverse dimensions and p-values at different time points

T0-T1	1st Premolar		2nd Premolar		1st Molar	
Landmark	Mean Change (mm)	p-value	Mean Change (mm)	p-value	Mean Change (mm)	p-value
Nasal Floor External	-0.85	0.640	-0.62	0.563	0.48	0.14
Nasal Floor Internal	1.65	0.007	2.04	0.009	1.71	0.003
Palate External	3.45	0.003	1.23	0.069	1.65	0.003
Palate Internal	3.00	<.0001	2.55	0.001	2.26	0.0003
CEJ External	6.64	<.0001	6.00	<.0001	6.69	<.0001
CEJ Internal	6.78	<.0001	6.31	<.0001	6.92	<.0001
Buccal Cusp	8.02	<.0001	7.97	<.0001	7.80	<.0001
Lingual Cusp	7.52	<.0001	8.16	<.0001	7.80	<.0001
T1-T2	**1st Premolar**		**2nd Premolar**		**1st Molar**	
Landmark	Mean Change (mm)	p-value	Mean Change (mm)	p-value	Mean Change (mm)	p-value
Nasal Floor External	-0.53	0.742	-1.50	0.090	-0.16	0.829
Nasal Floor Internal	0.16	0.655	-0.34	0.189	-0..39	0.175
Palate External	-0.53	0.342	-0.02	0.978	-0.76	0.101
Palate Internal	-0.87	0.009	-0.35	0.397	-0.25	0.602
CEJ External	-0.23	0.715	0.48	0.339	0.25	0.582
CEJ Internal	-0.40	0.334	0.35	0.492	-0.57	0.167
Buccal Cusp	-0.46	0.390	0.62	0.338	-0.81	0.200
Lingual Cusp	-0.22	0.670	0.22	0.736	-0.83	0.172
T0-T2	**1st Premolar**		**2nd Premolar**		**1st Molar**	
Landmark	Mean Change (mm)	p-value	Mean Change (mm)	p-value	Mean Change (mm)	p-value
Nasal Floor External	-0.64	0.770	-1.34	0.328	0.39	0.632
Nasal Floor Internal	1.81	0.005	1.70	0.016	1.10	0.920
Palate External	2.90	0.003	1.14	0.261	0.67	0.209
Palate Internal	2.28	0.002	2.15	0.001	2.06	0.002
CEJ External	5.68	<.0001	6.16	<.0001	6.63	<.0001
CEJ Internal	5.67	<.0001	6.41	<.0001	6.07	<.0001
Buccal Cusp	6.81	<.0001	8.30	<.0001	6.60	<.0001
Lingual Cusp	6.61	<.0001	8.14	<.0001	6.56	<.0001

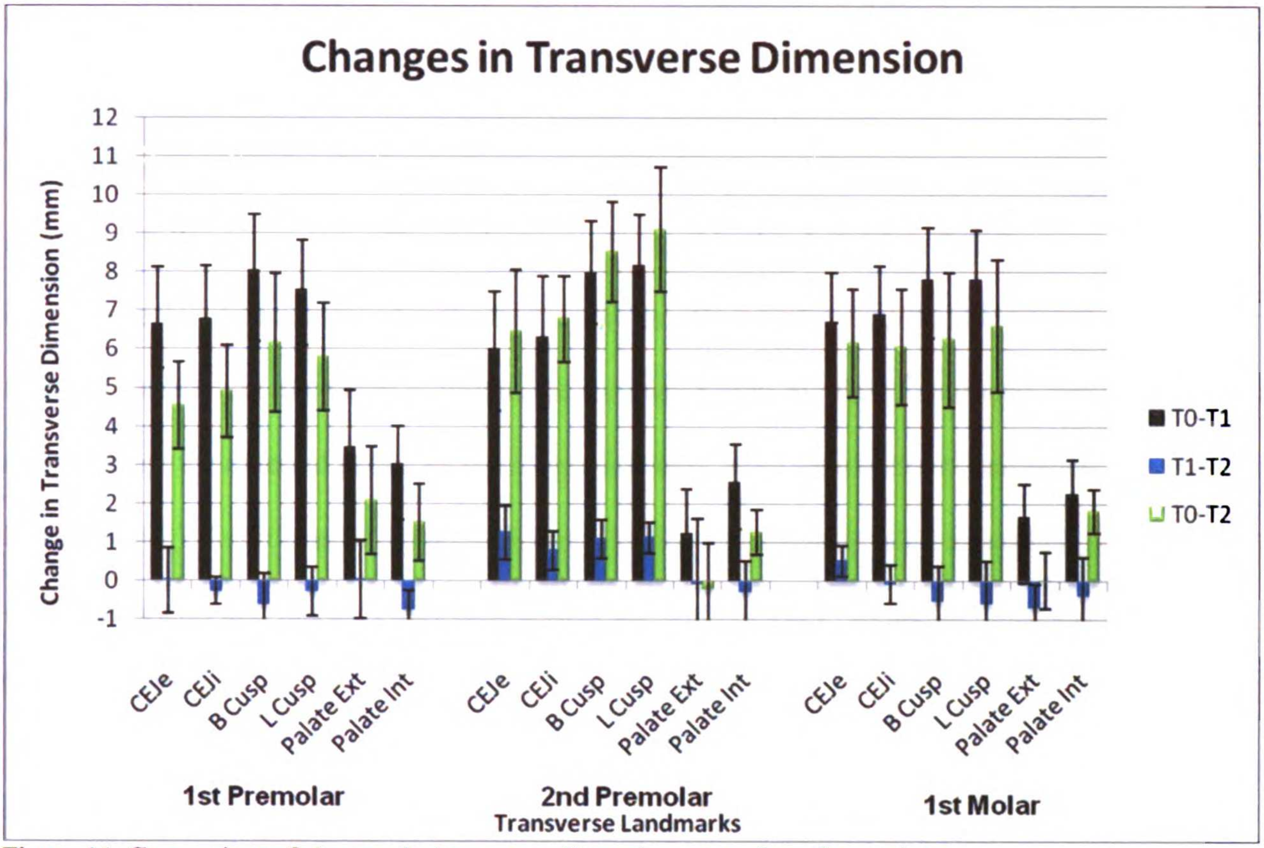

Figure 14: Comparison of changes in transverse dimensions at various time-points

Comparison of expansion at different levels of the maxilla

Changes in transverse dimensions at the level of the dental arch (CEJ and cusps) were remarkably larger than that observed at the maxillary base. Additionally, there were significant differences in transverse expansion noted in posterior or sagittal direction. When comparing the pre-treatment time point (T0) to the immediate post-expansion time point (T1), the first premolar had a significantly higher percentage of expansion at the level of the palate, CEJ, and buccal cusp when compared to both the second premolar and the first molar, while all other measurements showed no difference (Table 6). Additionally, the first premolar exhibited a greater percentage of expansion of all the palatal and dental measurements when compared to the first molar. The non-abutment, second premolar showed significantly greater increases in the buccal and lingual cusp dimensions than the 1st molar.

When comparing the immediate post-expansion time point to the six-month post-expansion follow up, no significant changes were seen in the skeletal or dental measurements when compared to the first premolar. No significant differences were found in the amount of change in transverse dimension between the 1st premolar and 1st molar except the external palate increased significantly more than at the 1st premolar level ($p<.001$) Additionally, the second premolar had significantly more expansion at the buccal cusps and lingual cusps than seen at the level of the 1st molar ($p= 0.03$ and 0.05 respectively).

Table 6: Comparison of expansion of different levels of the maxilla at different timepoints

	T0-T1		T1-T2		T0-T2	
1st Premolar vs 2nd Premolar	Mean Difference (mm)	p-value	Mean Difference (mm)	p-value	Mean Difference (mm)	p-value
Nasal Floor Ext	-0.38	0.926	0.56	0.634	0.90	0.605
Nasal Floor Int	-1.98	0.229	0.11	0.816	0.51	0.253
Palate External	5.80	0.008	1.76	0.076	-0.50	0.514
Palate Internal	6.71	0.043	0.13	0.804	-0.52	0.334
CEJ External	2.90	0.039	-0.09	0.904	-0.67	0.259
CEJ Internal	7.31	0.006	-0.47	0.456	-0.85	0.034
Buccal Cusp	3.05	0.045	-1.00	0.260	-1.11	0.065
Lingual Cusp	2.54	0.189	-0.90	0.2910	-0.34	0.519
	T0-T1		T1-T2		T0-T2	
2nd Premolar vs 1st Molar	Mean Difference (mm)	p-value	Mean Difference (mm)	p-value	Mean Difference (mm)	p-value
Nasal Floor Ext	-1.88	0.378	-1.92	0.102	-1.39	0.193
Nasal Floor Int	3.06	0.246	0.60	0.209	0.05	0.902
Palate External	0,04	0.971	0.47	0.550	0.74	0.713
Palate Internal	3.11	0.224	0.09	0.850	-0.10	0.286
CEJ External	0.48	0.607	-0.47	0.363	0.23	0.575
CEJ Internal	0.19	0.859	0.33	0.490	0.92	0.038
Buccal Cusp	2.92	0.024	1.70	0.030	1.43	0.012
Lingual Cusp	5.10	0.007	1.58	0.050	1.05	0.119
	T0-T1		T1-T2		T0-T1	
1st Premolar vs. 1st Molar	Mean Difference (mm)	p-value	Mean Difference (mm)	p-value	Mean Difference (mm)	p-value
Nasal Floor Ext	-2.25	0.575	-1.33	0.4791	-0.53	0.738
Nasal Floor Int	1.08	0.652	0.71	0.186	0.56	0.310
Palate External	5.76	0.010	2.23	<0.001	0.23	0.713
Palate Internal	9.82	0.021	-0.22	0.725	-0.61	0.286
CEJ External	3.38	0.005	-0.61	0.170	-0.51	0.280
CEJ Internal	7.51	0.004	-0.01	0.983	0.14	0.661
Buccal Cusp	5.97	0.001	0.61	0.303	0.39	0.376
Lingual Cusp	7.64	0.003	0.51	0.333	0.76	0.068

Comparison of axial inclinations of the teeth

Rapid maxillary expansion using the Hyrax appliance led to significant buccal tipping of the posterior teeth. The first premolars showed statistically significant tipping of the left premolars ($p = 0.0237$; Table 7) and insignificant changes of the right premolars from T0 to T1($p = 0.4692$). There was no significant change in axial inclination of the teeth between immediate post-expansion and six-month post-expansion timepoints. The second premolars showed the most change in axial inclination of the teeth ($p = 0.0014$). The inclination did not change significantly from T1-T2 ($p = 0.544$). Although insignificant, the superimpositions showed that the second premolars appeared to upright from T1-T2. The crowns of the 2nd premolars tended to stay in the same place while the root moved buccally over the crown.

In a similar pattern as the 1st premolars, the first molars had a significant increase in axial inclinations from T0 to T1 ($p = 0.0149$) and did not show changes from T1-T2 ($p = 0.122$).

When the changes found among the teeth were compared statistically, the non-abutment 2nd premolar tipped significantly more than both the 1st premolars and the 1st molars from T0-T1 ($p = 0.0093$ and $p = 0.029$ respectively). There was no difference in the changes among the posterior teeth from T1-T2.

Table 7: Comparison of axial inclination of the teeth

	T0-T1		T1-T2		T0-T2	
	Mean Change (°)	p-value	Mean Change (°)	p-value	Mean Change (°)	p-value
1st Premolar R	3.79	0.024	0.42	0.841	1.71	0.485
1st Premolar L	1.21	0.469	0.38	0.860	2.83	0.243
2nd Premolar R	9.26	<0.001	0.49	0.760	7.92	0.003
2nd Premolar L	10.46	0.002	-1.88	0.325	9.08	0.002
1st Molar R	3.79	0.022	-2.75	0.052	1.81	0.330
1st Molar L	3.82	0.008	-2.19	0.193	1.25	0.489

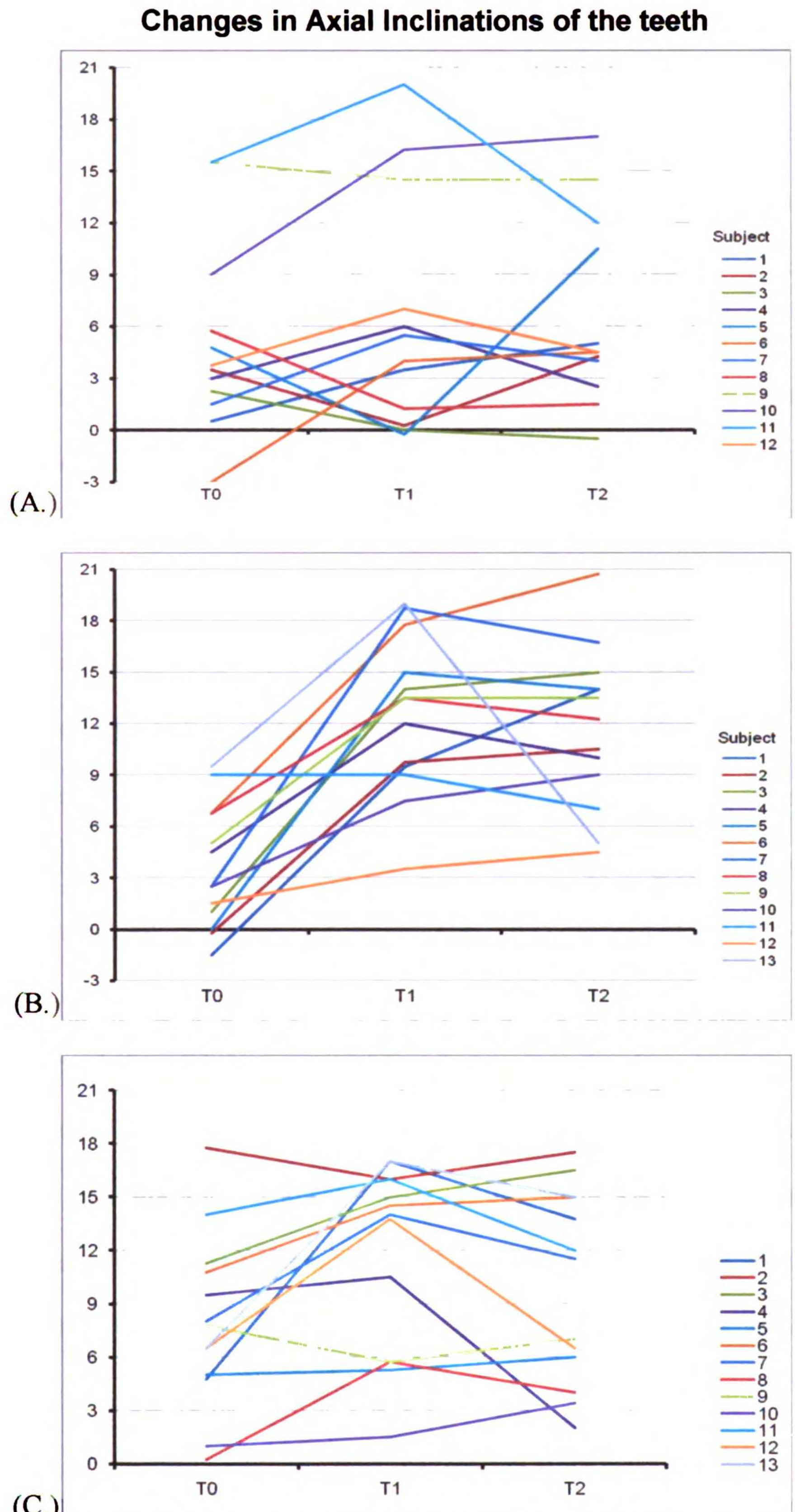

Figure 15: Changes in axial inclinations of the (A) 1st Premolar, (B) 2nd Premolar, and (C) 1st Molar

Patency of the midpalatal sutures and effects on buccal plate

The midpalatal suture was split to varying degrees in eleven of the fourteen subjects. All eleven of the subjects had visible clefting in the segmented sections immediately following active expansion, and five of the subjects showed clefting of the anterior alveolus up through the nasal floor. At the six-month follow up, all of the patients had bone fill in the area of the split with a large range of Hounsfield Units (HU) suggesting soft tissue and bone.

More interesting, however, were the effects of RME on the buccal plates of the maxilla. Unlike other studies, there was very little bending or flexing of the alveolus. Despite successful splitting of the mid-palatal suture, there was a 49% incidence of dehiscence and fenestration of the roots of the teeth (Table 8). Nineteen out of the fifty-five teeth were 1st premolars with dehiscence through the buccal plate. Fourteen first molars showed similar dehiscence to the 1st premolar. Surprisingly, the third most common sequelae was dehiscence of the canines. Forty-one out of the fifty-five teeth (80%) involved were abutment teeth included in the appliance.

The incidence of dehiscence and fenestration correlated moderately with splitting of the mid-palatal suture. However there were three subjects with similar buccal plate findings who exhibited successful splitting of the midpalatal suture. Unfortunately, only two of the fourteen subjects had improvement of the dehiscence and fenestration at the six-month follow up time point. The improvement occurred at the first premolars in both subjects.

Table 8: Dehiscence and fenestration occurrence

Pt #	Split	Dehiscence				Fenestration				Improvement	Total
		C	1st PM	2nd PM	1st M	C	1st PM	2nd PM	1st M		
1	Y	0	0	0	0	0	0	0	0	**No**	**0**
2	Y	0	0	1	0	0	0	0	0	**No**	**1**
3	N	2	2	0	0	0	0	0	2	**No**	**6**
4	N	0	1	0	2	0	1	0	0	**Yes- 1st PM**	**4**
5	N	2	2	0	2	0	0	0	0	**No**	**6**
6	Y	0	2	0	2	0	0	0	0	**No**	**4**
7	Y	2	1	0	1	0	1	0	1	**No**	**6**
8	Y	2	2	0	1	0	0	0	0	**No**	**5**
9	Y	0	2	0	1	0	0	0	0	**Yes-1st PM**	**3**
10	Y	0	2	0	0	0	0	0	0	**No**	**2**
11	Y	2	2	0	2	0	0	0	0	**No**	**6**
12	Y	0	0	0	0	0	2	0	0	**No**	**2**
13	Y	0	1	0	1	0	1	0	0	**No**	**3**
14	Y	2	2	1	2	0	0	0	0	**No**	**7**
Total	**11**	**12**	**19**	**2**	**14**	**0**	**5**	**0**	**3**	**2**	**55**

0= None of designated teeth have dehiscence or fenestration

1= One of the designated teeth (right or left) have dehiscence or fenestration

2= Both right and left teeth have dehiscence or fenestration

Discussion

Although many studies of rapid maxillary expansion exist, few have used cone beam computed tomography technology. This study has an advantage in that it utilized this latest technology and found some novel outcomes. Given that few true three dimensional analyses of rapid maxillary expansion exist in the literature, the techniques used in this study were original. To that end, they were described in great detail in the Materials and Methods section so that others can repeat the method in future projects. Although the software used in this study was cumbersome, the technique was shown to produce reliable results.

The CBCT technology gave us the ability to analyze the data in several different forms to confirm our results. This was most important in evaluating the effects of rapid maxillary expansion on the supporting periodontal structures. These results were so impressive and became a major a focus of the study. Other studies have touched on the issue of dehiscence and grossly underestimated the effects when compared to the dehiscence and fenestration rate of forty-nine percent in this study.[29-31,34,35] These results, in addition to the high rate of mid-palatal suture split, suggest that the major resistance to rapid maxillary expansion is most likely in the circum-maxillary sutures. More disconcerting, however, was that the study showed minimal resolution of these side effects from T1-T2. The clinical implications of such results could change the current protocols on rapid maxillary expansion.

The sample size of fourteen was a substantially larger sample size than used in similar three dimensional studies.[32,35] This afforded more power to the statistical analyses to reveal significant differences when they exist. Additionally, the age group of the sample varied greatly from 13 to 16.5 years of age, and some might argue that the cohort was older than ideal for rapid maxillary expansion. Unfortunately, the majority of the patients at the University of California, San Francisco Orthodontic Clinic are in their permanent dentition at the time of the first clinical exam, limiting us to this age range. At this point, the data gathered will serve as important pilot data from which a larger, more diverse, sample can be compared in the future.

Our results indicate that rapid maxillary expansion was very effective at increasing transverse dimensions in all of the areas measured except the external nasal floor. This finding is similar to previous studies.[1,6,9,22,29-33,35,53] The exception of the external nasal floor is most likely explained by the poor intra-rater reliability in identification of this landmark. It was difficult to consistently make the same measurement of the external nasal floor due to the convexity of the landmark and variable densities of the region.

The pattern of skeletal and dental expansion was similar to what has been observed in previous studies.[1,7,10-12,21,29] The amount of expansion decreased from the anterior to the posterior and inferior to superior regions of the maxilla. This indicates that the anterior dentition provides the least resistance to expansion while the skeletal structures of the maxilla in the nasal regions provide the greatest resistance. The palate showed intermediate results when compared to the dentition and nasal structures.

Unlike previous investigations, this study included the use of full fixed appliances between the immediate post-expansion time-point and the six-month follow-up. Using this protocol allowed us to observe the true changes to the dentition and periodontal structures following expansion protocols commonly used in clinical settings. Interestingly, the six-month follow-up data revealed different results than observed in previous studies. Most studies show statistically significant relapse of the transverse dimensions and inclination of the dentition.[29] Our study revealed statistically insignificant relapse of the expansion at the level of the abutment teeth, and significant increases in transverse dimension in the second premolars. The fixed appliances used between T1-T2 likely maintained the expansion and, in some instances, increased the transverse dimensions further damaging the buccal plate. The increase in dimensions at the second premolars resulted from up-righting of the root from expression of the prescription in the brackets.

Expansion of the maxilla also elicited statistically significant changes in the angulation of the posterior teeth. This suggests that significant increases in transverse dimension are largely due to tipping and subsequent up-righting of the roots of the dentition. The results were similar to those seen in the study by Garib[32] in that the abutment teeth tipped less than the non-abutment 2nd premolars. The rigid Hyrax appliance was fixed to the 1st premolars and 1st molars, and resisted large changes in angulation. This set up lead to greater translation of the supporting teeth through the buccal bone. Unlike the abutment teeth, the 2nd premolars were tipped buccally as a result of the simple force applied at substantial distance from the center of resistance, which created a moment leading to increases in buccal angulation.

One potential pitfall of the study was that the dentition was used as one of the orientation planes prior to segmentation and data gathering. The teeth changed position throughout treatment with the Hyrax appliance and full fixed appliances, possibly altering the occlusal plane used for orientation. However, the changes seen in the orientation of the occlusal plane, if any, were thought to minimal from T0 to T1 due to the rigid nature of the Hyrax appliance limiting second and third order movements. The changes seen from immediate post-expansion to the six-month follow-up were also minimal, but quite valuable in understanding the full spectrum of changes from such treatment.

A second limitation of this study is the number of teeth selected for study. Previous studies by Garib[32,35] examined the effects of RME on the 1st premolar, 2nd premolar, and 1st molar. This would be intuitive given that these are the teeth intimately associated with the appliance. However, given the high incidence of dehiscence and fenestration of the canines, it would have been valuable to have measured all of the changes seen here as well.

Directions for future study

Our results indicate that rapid maxillary expansion is an effective method for increasing transverse dimensions of the dentition and palate. At this point, it is important to further determine the cause of the dehiscence and fenestration through the buccal plate. It is clear that we do not fully understand the relationship between successful expansions with age or the structural resistance to rapid maxillary expansion in the circum-maxillary sutures. Additional studies with greater number of subjects and different appliance designs may shed some light on the limitations of rapid maxillary expansion. Furthermore, the outcomes of surgical intervention, such as surgically assisted rapid maxillary expansion, will help to explain the role that the sutures play in the restrictions of RME.

As three-dimensional cone beam computed tomography technology improves, the resolution of the images will improve as well. Further studies of this technique will clearly define limits of measurements taken from these scans, and will enable us to understand the value in the measurements taken. Additionally, it would be advantageous to be able to quantify the bone density in the midpalatal suture and buccal plates in future studies to determine if the initial quality of the bone is an indicator of successful RME.

Conclusions

- RME significantly increased all transverse dimensions of the maxilla, except for the external nasal floor, decreasing in magnitude from the anterior to posterior and inferior to superior regions of the maxilla.
- Although treatment with the Hyrax appliance leads to splitting of the mid-palatal suture, significant increases in transverse dimension are largely due to tipping and subsequent up-righting of the roots of the dentition.
- High incidence of dehiscence and fenestration suggest that the resistance to RME may lie in the circumaxillary sutures in addition to the mid-palatal suture

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Appendix

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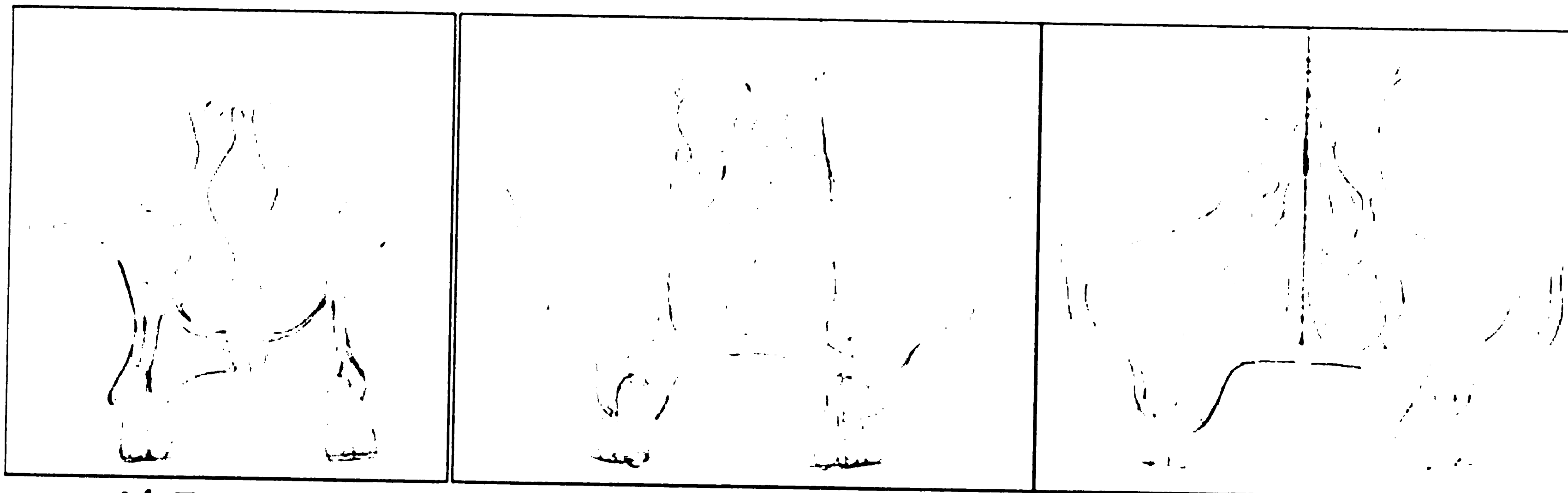

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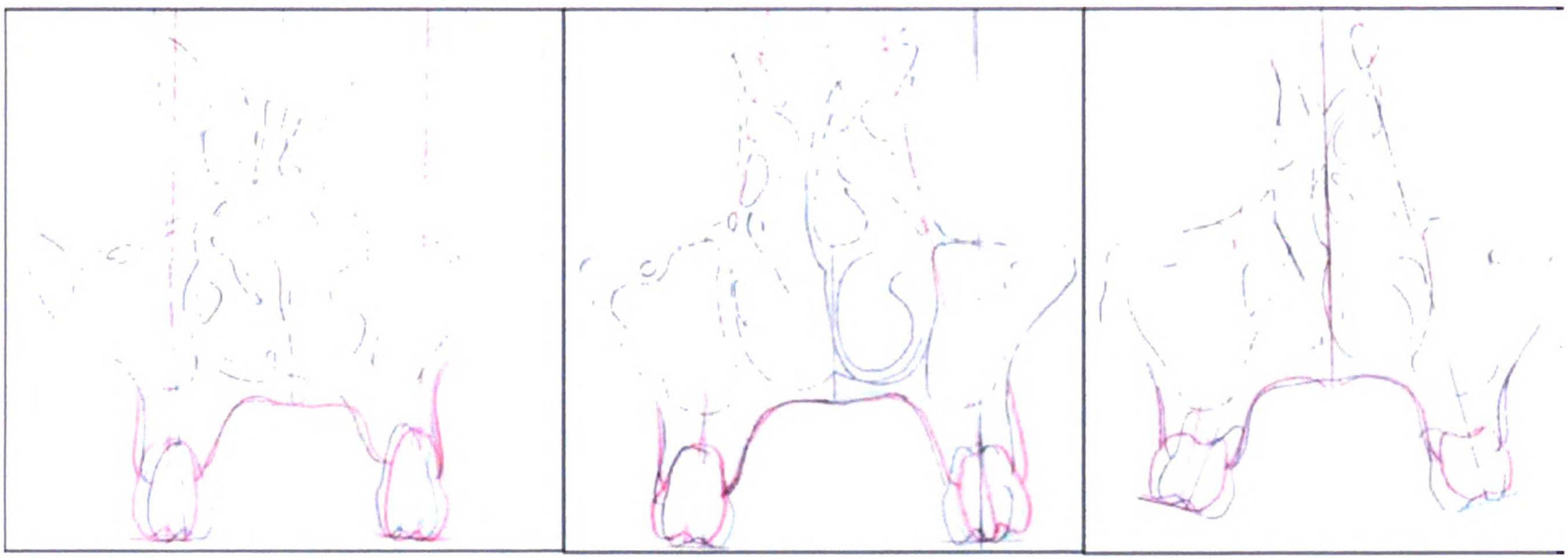

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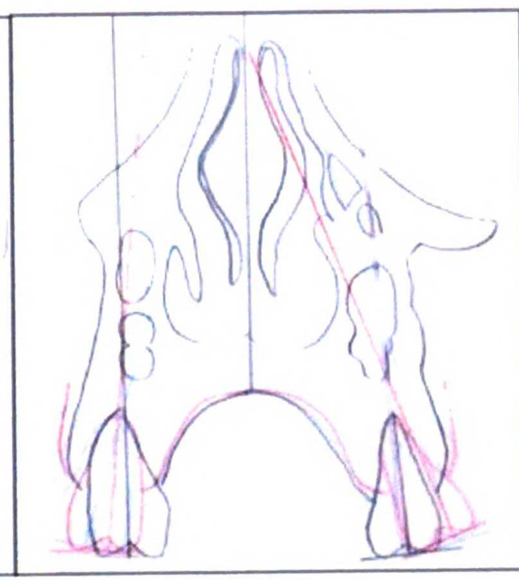

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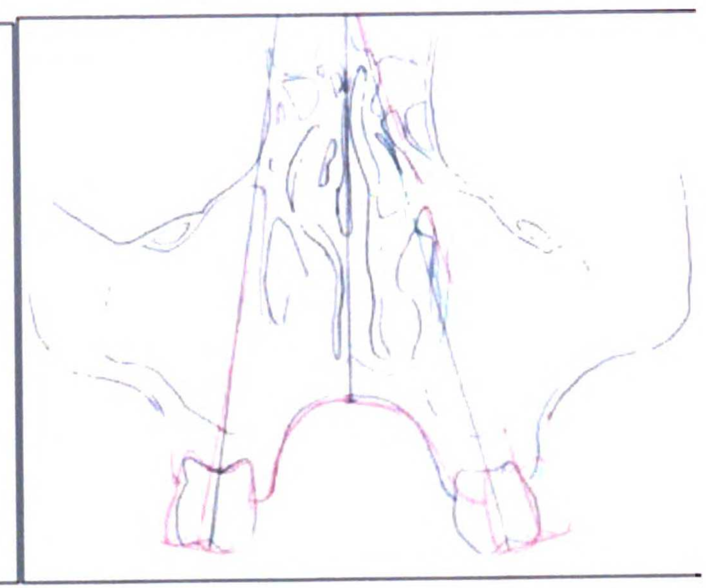

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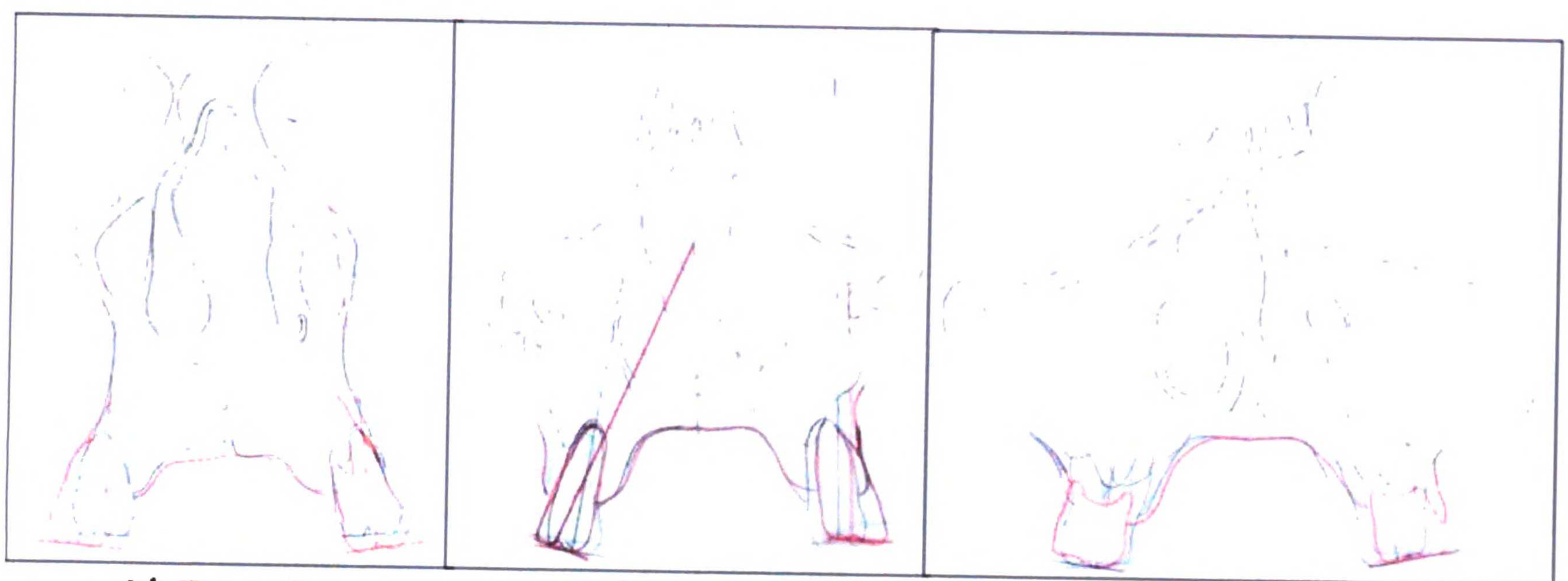

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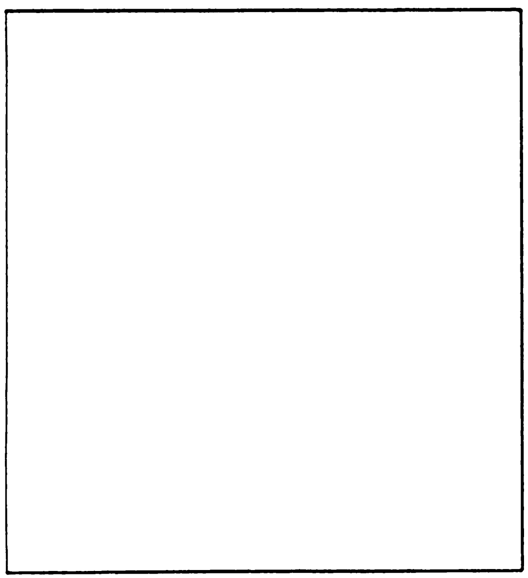

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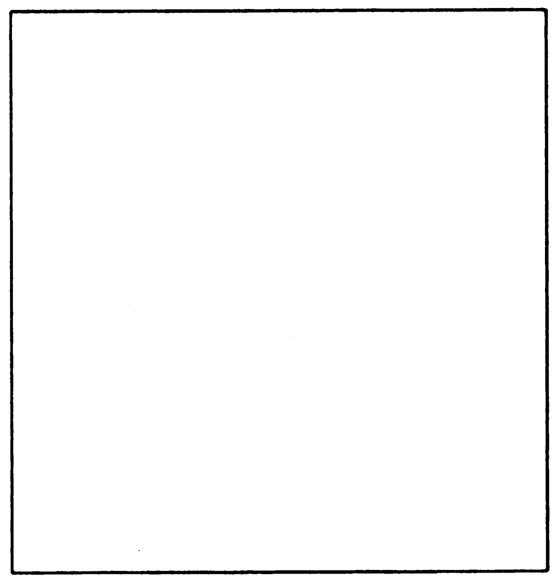

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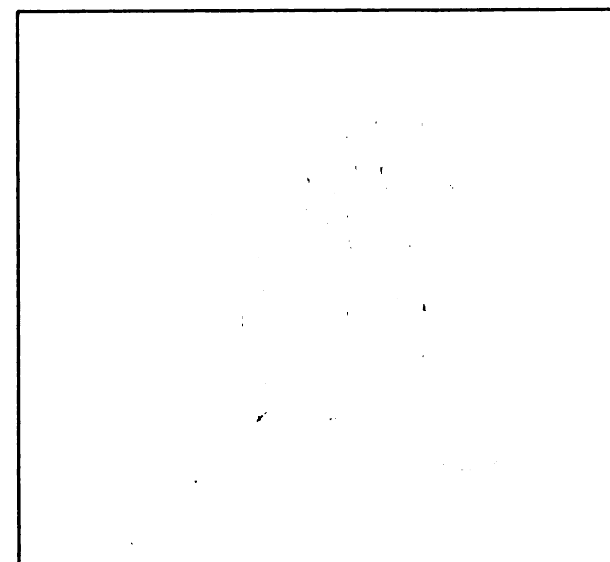

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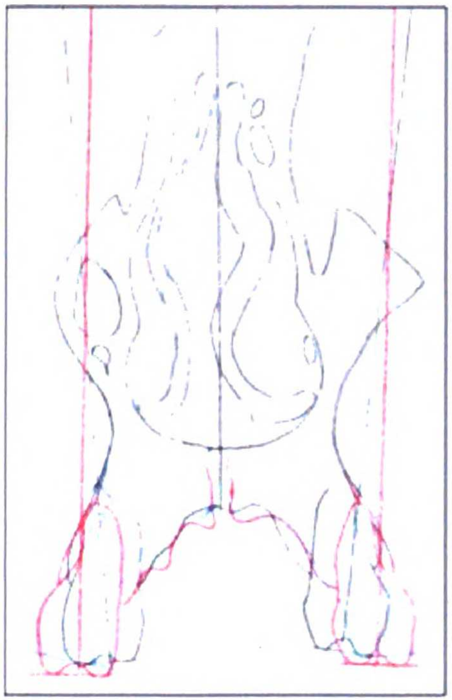

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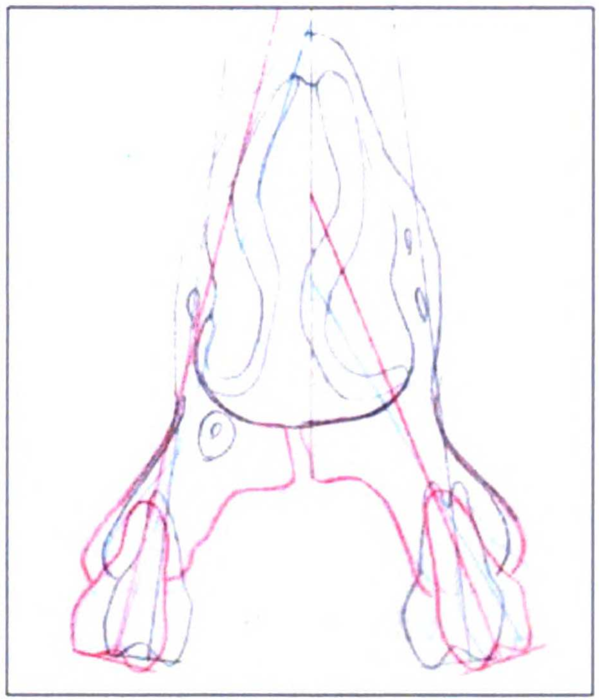

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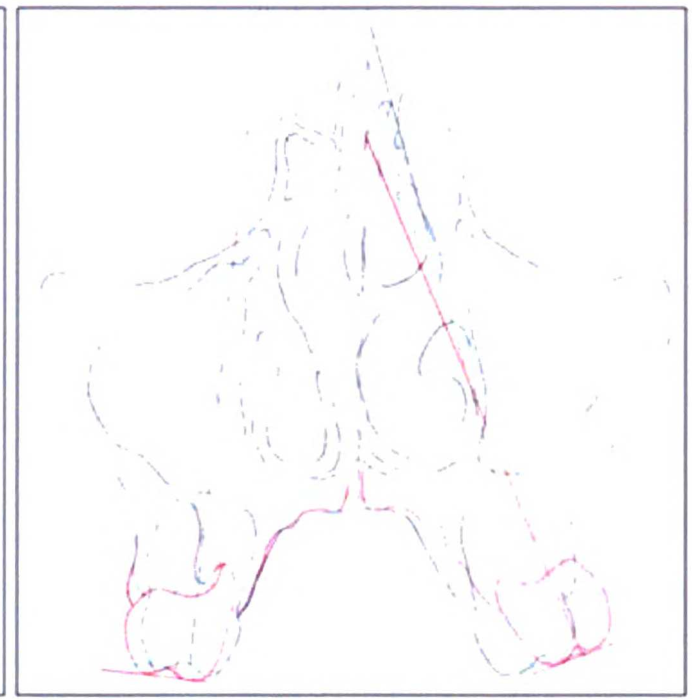

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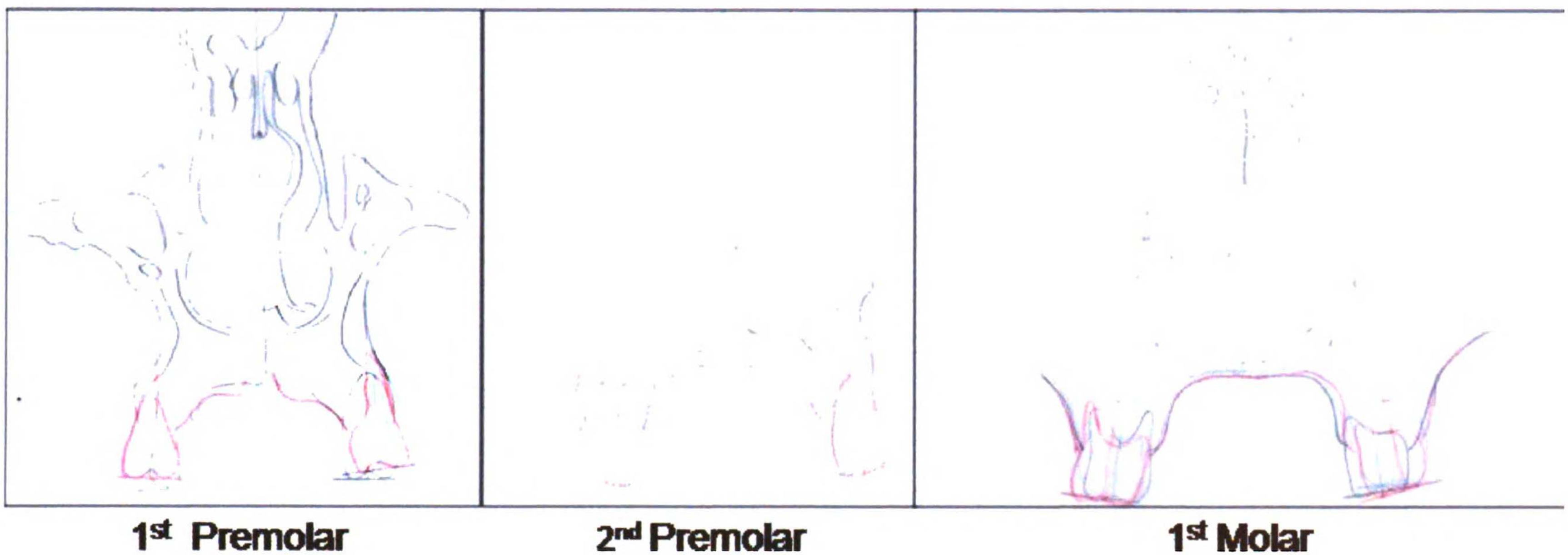

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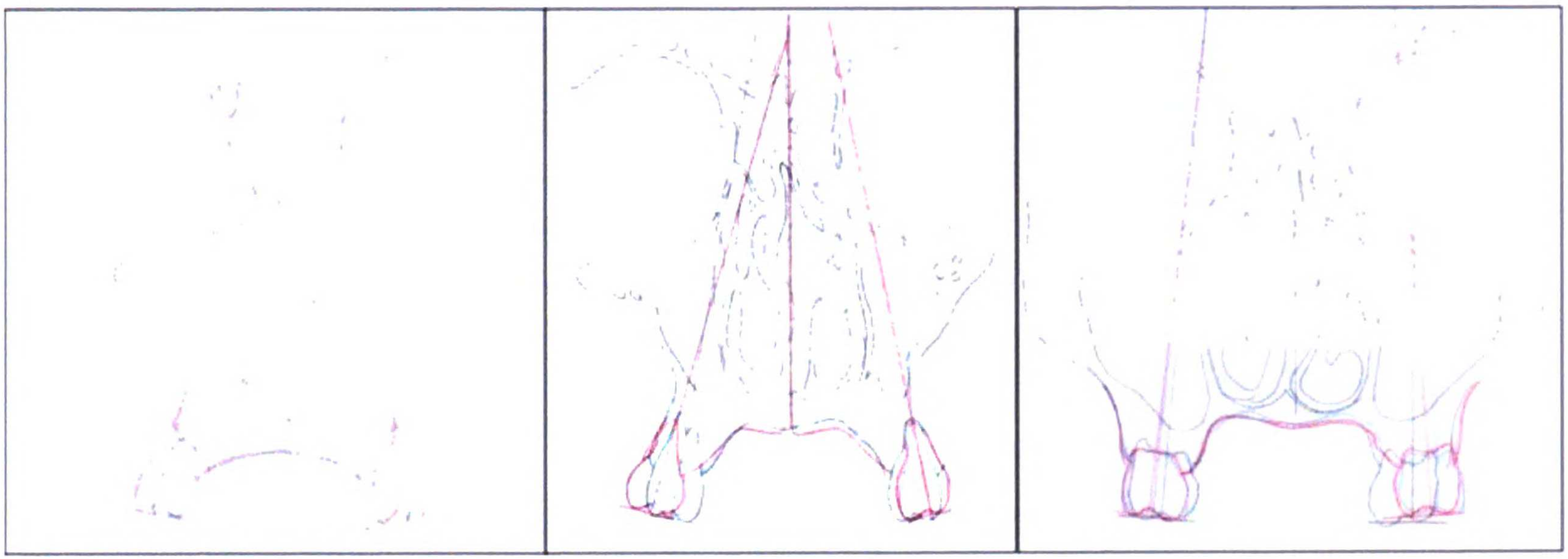

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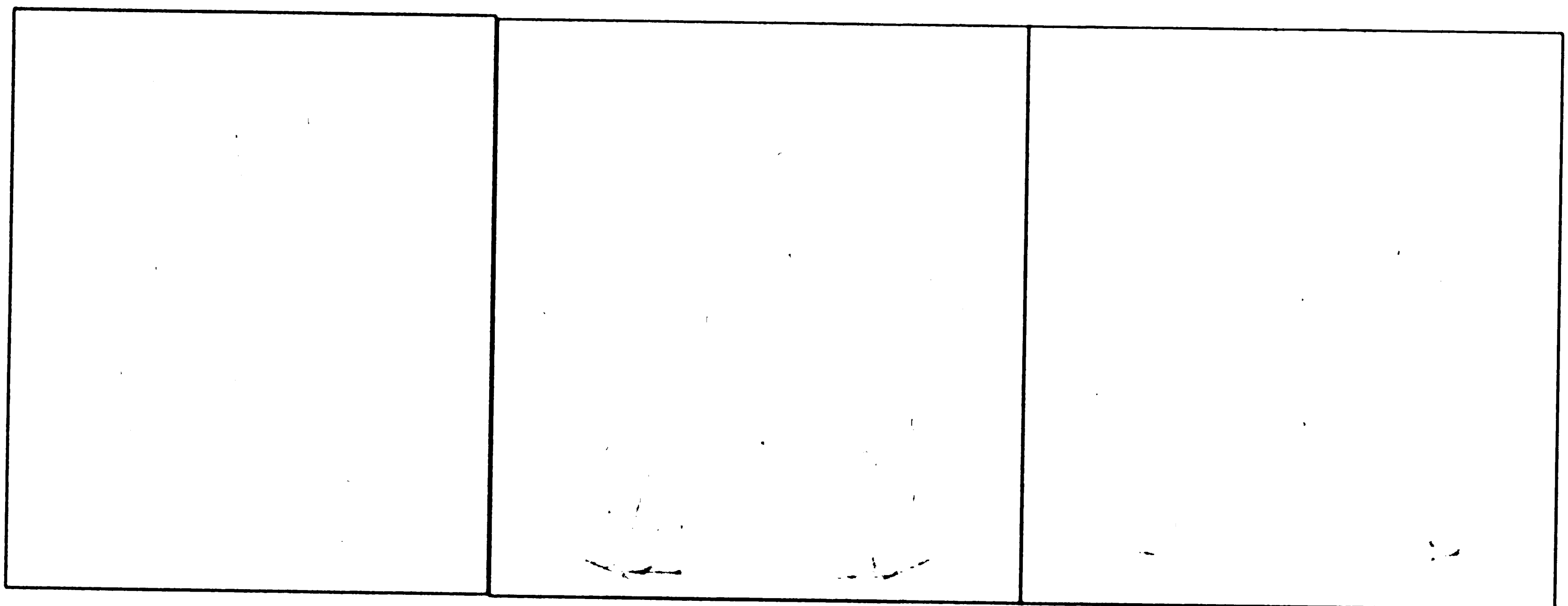

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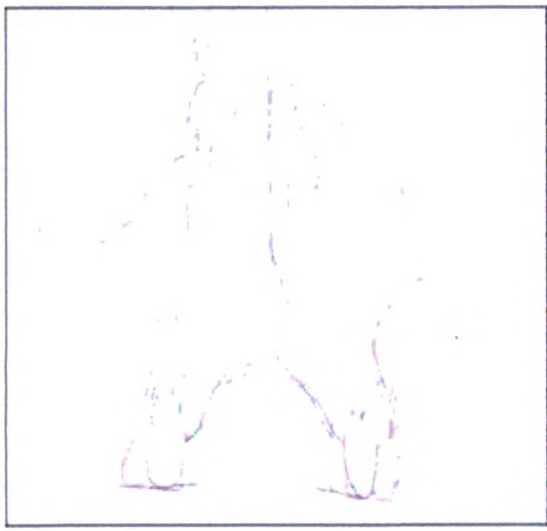

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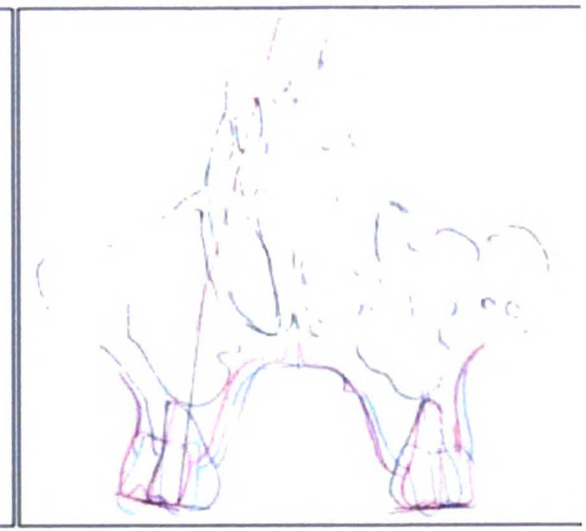

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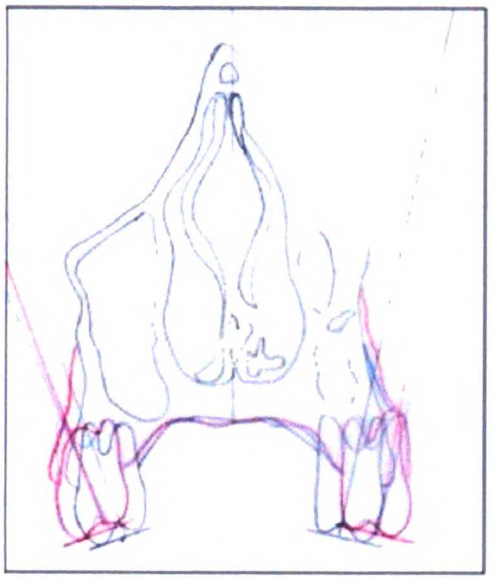

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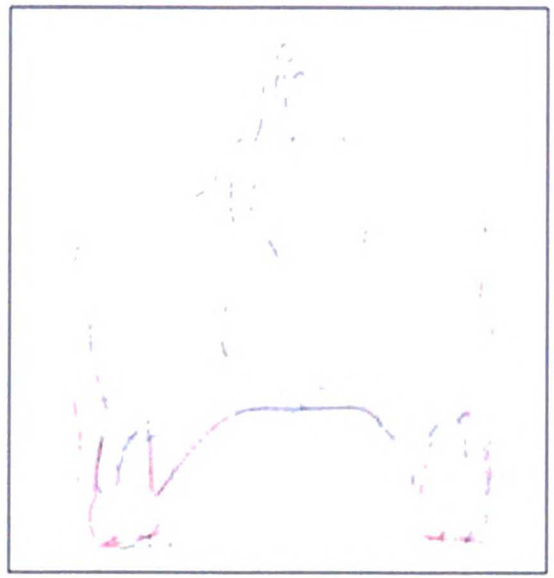

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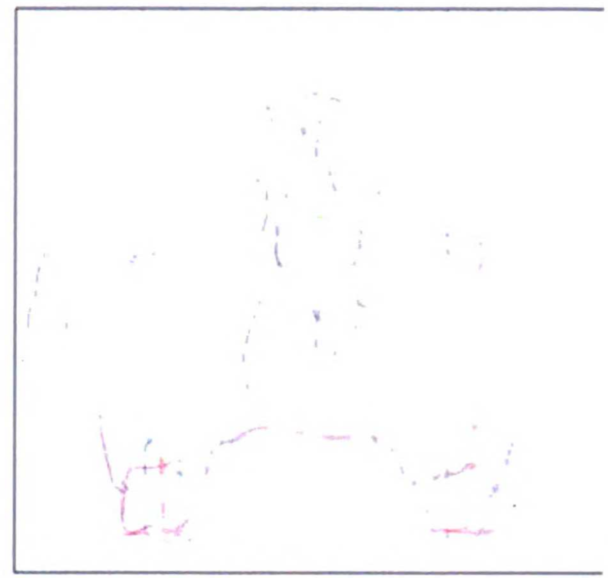

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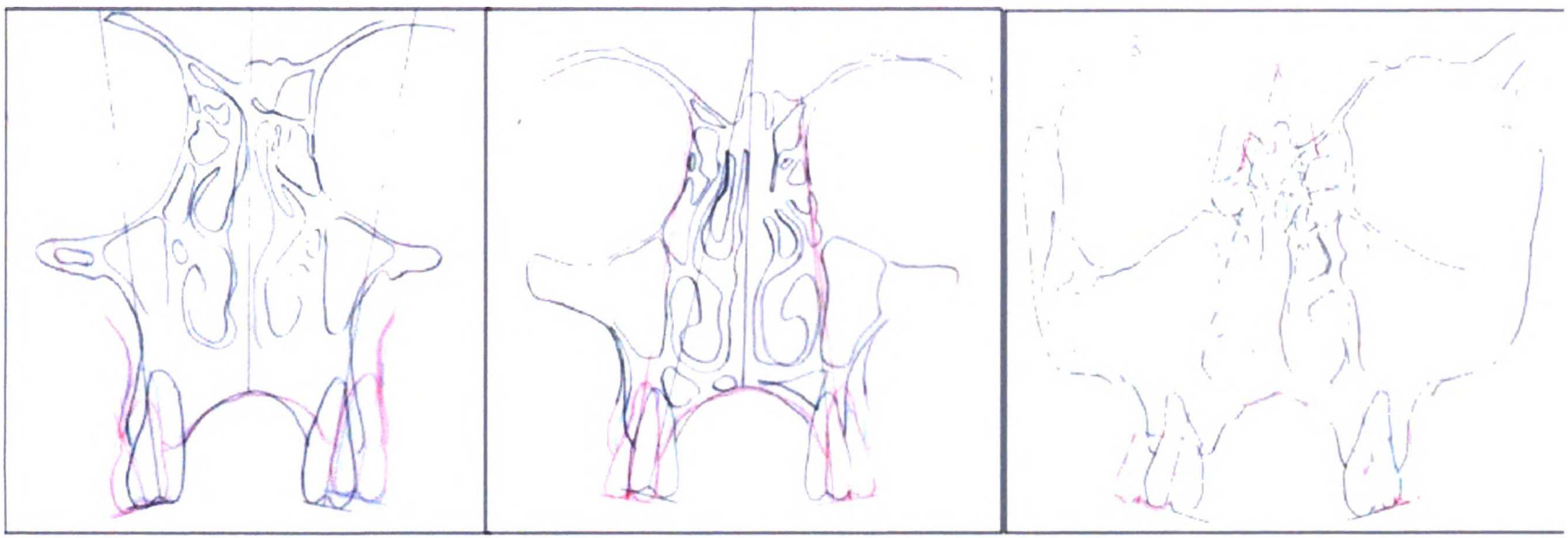

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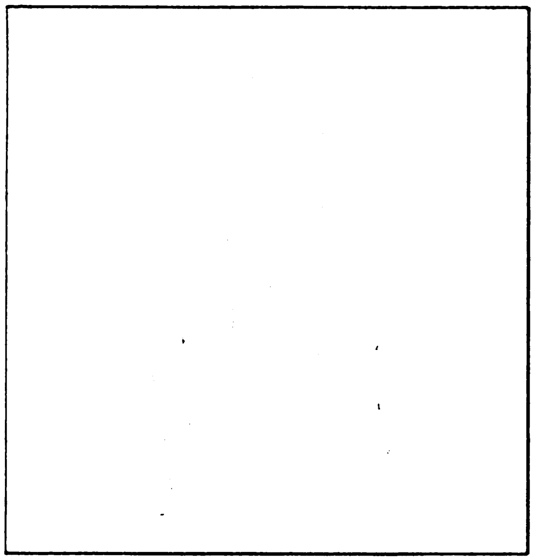

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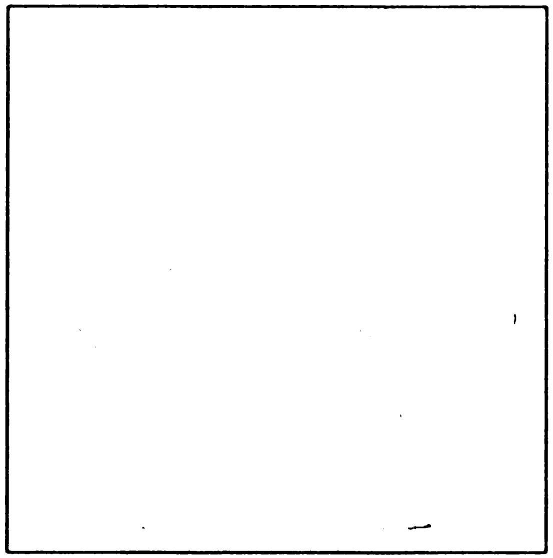

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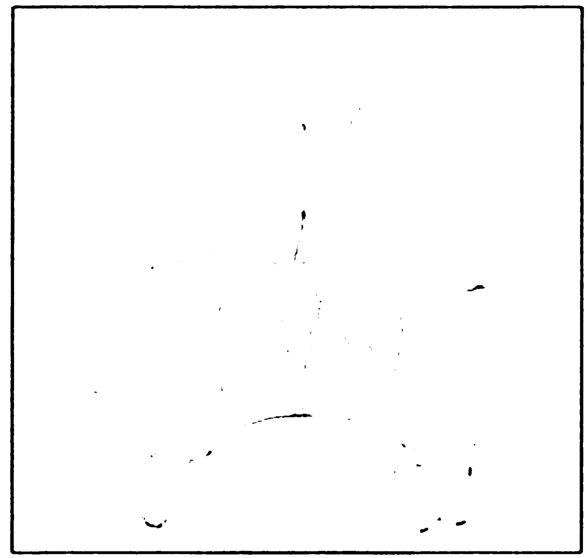

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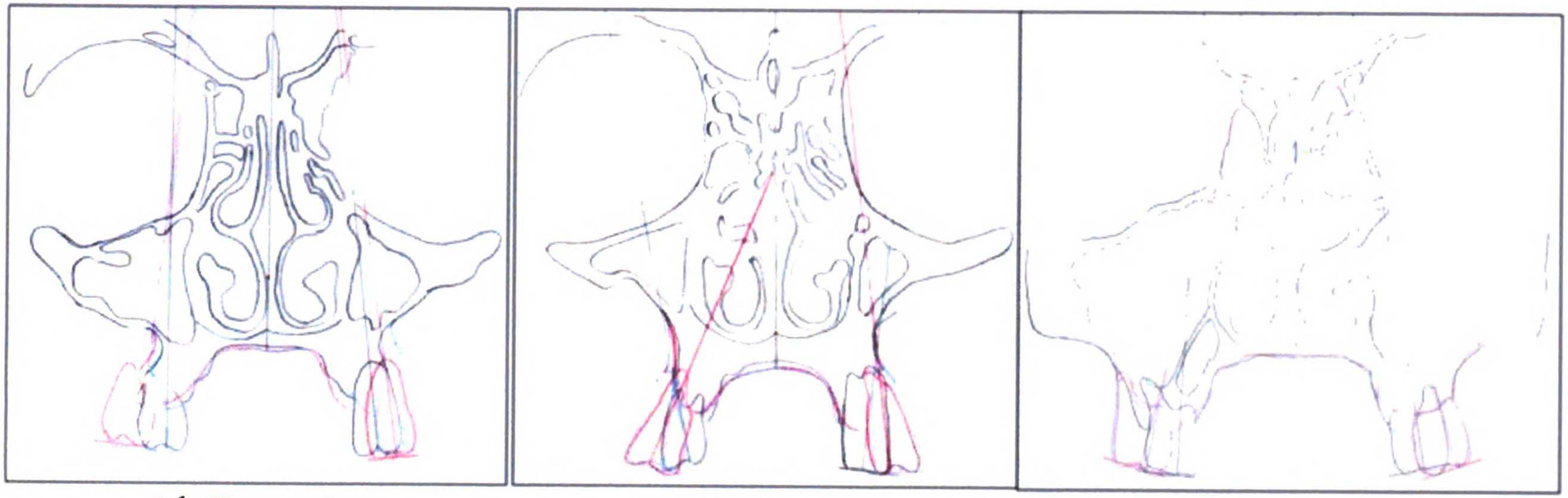

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