MAXILLARY TRANSVERSE COMPARISON OF SKELETAL CLASS I AND CLASS III PATIENT POPULATIONS USING CONE BEAM COMPUTED TOMOGRAPHY

A THESIS

Presented to the Faculty of

Uniform Services University of the Health Sciences

In Partial Fulfillment

Of the Requirements

For the Degree of

MASTER OF SCIENCE

By

Breck Stephen Brewer, BS, DDS

San Antonio, TX

April 13, 2012

MAXILLARY TRANSVERSE COMPARISON OF SKELETAL CLASS I AND CLASS III PATIENT POPULATIONS USING CONE BEAM COMPUTED TOMOGRAPHY

Breck Stephen Brewer

APPROVED:

Ricardo Vendrell

Ricardo Vendrell, D.D.S., Supervising Professor

Curtis M. Marsh, D.D.S., M.S.

Brent J. Callegari, D.D.S., M.S.D.

Drew W. Fallis, D.D.S., M.S.

April 12, 2012

Date

APPROVED:

Thomas R. Schneid, D.M.D., M.S.
Dean, Air Force Post-Graduate Dental School

This thesis is dedicated to my family. Countless hours of work have often come at the expense of those I care about most. Thank you Lauren, my love, for your unending support of me during these academic endeavors over the years. Thank you Dillon, Teague, Sadie and Claire for keeping me focused on what matters, the true joys of life. Thank you to my mother and father for providing the opportunities I needed to get to this point in life, for continually expecting great things. But it is only with the strength and wisdom provided through our Lord Jesus Christ that this and everything else that I have accomplished is possible.

ACKNOWLEDGEMENTS

I would like to thank the supporting staff at the Tri-Service Orthodontic Residency Program. In particular, Dr. Ricardo Vendrell has been inherently involved with this project and has helped provide the insight needed to see through its completion. Thank you to Dr. Stephen Schultz for the statistical support. Thank you to Dr. Brent Callegari for the continued encouragement needed to reach each “milestone”.

I would also like to thank Drs. Drew Fallis and Curtis Marsh for the outstanding mentorship during the entire orthodontic program.

ABSTRACT

Introduction: It has been hypothesized that if hypoplasia of the maxilla occurs in one plane of space, such as the sagittal plane of many skeletal Class III patients, it will occur in multiple planes of space, including transverse. With the advent of Cone-Beam Computed Tomography (CBCT), better assessment of skeletal transverse widths can be appreciated using various landmarks in the maxilla. The aim of this study was to compare the linear widths of anterior and posterior maxillary skeletal landmarks and their subsequent anterior-to-posterior ratios in a group of Class I and Class III patients using pretreatment CBCT images. **Method**: Pretreatment CBCT images of forty-nine skeletal Class I patients with normal maxillary growth and thirty Class III patients with maxillary sagittal hypoplasia were evaluated. Linear transverse measurements were determined from anterior and posterior maxillary landmarks using coronal CBCT slices. **Results**: Widths measured between maxillary canine root apices were significantly narrower for Class III patients, while widths measured between the greater palatine foramina were significantly wider for Class III patients compared to the Class I population ($P < .05$). No statistically significant differences were noted between the populations in first molar palatal root apices or infraorbital foramina width. All four anterior-to-posterior (A-P) ratios of widths demonstrated a greater maxillary skeletal tapering from posterior to anterior in Class III patients with three out of the four ratios having a statistically significant difference. **Conclusions**: The Class III group, defined as being deficient in sagittal maxillary skeletal growth, also had transverse skeletal

deficiency in the anterior maxilla. However, unexpectedly, this same population showed increased transverse width measured in the posterior maxilla compared to the Class I group. When comparing A-P maxillary width ratios, the Class III group proved to have a more tapering skeletal form.

TABLE OF CONTENTS

Page

Title………………………………………………………………………….. i

Approval…………………………………………………………………….. ii

Dedication………………………………………………………………… iii

Acknowledgements……………………………………………………… iv

Abstract…………………………………………………………………… v

Table of Contents……………………………………………………….... vii

List of Figures…………………………………………………………… viii

List of Tables……………………………………………………………….. ix

I. BACKGROUND AND LITERATURE REVIEW……………………………. 1

II. OBJECTIVES

A. Overall Objective……………………………………………………. 12

B. Specific Hypothesis…………………………………………………. 12

III. MATERIALS AND METHODS

A. Experimental Design……………………………………………….. 13

B. Statistical Management of Data…………………………………… 23

IV. RESULTS………………………………………………………………. 24

V. DISCUSSION…………………………………………………………… 31

VI. CONCLUSION…………………………………………………………. 42

VII. LITERATURE CITED………………………………………………… 60

LIST OF FIGURES

Page

Figure 1 Anterior Landmark: Canine root apices (CRA)………………..… 17

Figure 2 Anterior Landmark: Piriform or nasal orifice at the widest point (Pf) ……………………………………………………….… 18

Figure 3 Anterior Landmark: Infraorbital foramina (IF)………………... 19

Figure 4 Posterior Landmark: Maxillary first molar palatal root apices (MRA)………………………………………………………… 20

Figure 5 Posterior Landmark: Greater palatine foramina (GPF) …….. 21

Figure 6 Posterior Landmark: Buccal Point or intersection of maxillary tuberosity and zygomatic buttress at level of first molar mesiobuccal root (BP)………………………………………... 22

Figure 7 Quartile Comparison of A-P ratios based on transverse measurements of four landmarks for Class I (in green) and Class III (in red) groups……………………………………… 29

LIST OF TABLES

		Page
Table I	Reliability of widths of Six Landmarks Measured From Initial Twenty Class I Group …………………….…………………	25
Table II	Comparisons of Linear Transverse Maxillary Skeletal Width Measurements in Class I and Class III Groups………………	28
Table III	Comparisons of Anterior-to-Posterior Transverse Ratios of Maxillary Skeletal Width Measurements in Class I and Class III Groups………………………………………………………	29
Table IV	Comparisons of Linear Transverse Maxillary Skeletal Width Measurements in Class I and Class III Groups (Male subjects only)………………………………………….……………	38
Table V	Comparisons of Anterior-to-Posterior Transverse Ratios of Maxillary Skeletal Width Measurements in Class I and Class III Groups (Male subjects only)……………………...………	39
Appendix A	Study Design algorithm………………………………………	43
Appendix B	Statistical Comparisons of inclusive characteristics in Class I and Class III Groups …………………………………………	44
Appendix C	Pilot Study Class I Results (Six Landmarks, n=20), Raw Data…………………………………………………………….	45
Appendix D	Class I Results (Four Landmarks, n=49), Raw Data…………	49
Appendix E	Class III Results (Four Landmarks, n=30), Raw Data……….	56

I. BACKGROUND AND LITERATURE REVIEW

A. Background

Traditionally, radiographic analysis in orthodontics has depended primarily on the lateral cephalometric analysis, which provides clinicians information in the antero-posterior and vertical dimensions. The obvious disadvantage to this is that the craniofacial complex is three-dimensional and this type of radiographic image produces only two of these dimensions. The third axis, the transverse plane, could only be radiographically analyzed using a frontal or posterior-anterior (PA) cephalometric image. Establishing diagnostic problems in this plane can be critical even in the youngest of patients as cessation of the transverse growth comes well before that of the antero-posterior or vertical dimensions and is largely unchanged after the age of seven (Lux 2004).

Ricketts developed a comprehensive frontal analysis using standard PA cephalometrics to aid in transverse diagnosis (Ricketts 1981). Maxillary width was determined using the distance between right and left jugal points (J-J), defined as the intersection of the maxillary tuberosity and zygomatic arch. Mandibular width was determined using the distance between antegonial notches (AG-AG). These two actual values were compared to the age-specific expected maxillomandibular transverse differential index to determine width discrepancies. A second method developed by Ricketts to determine transverse discrepancies was maxillomandibular width differentials. The distance from both right and left jugal points to a line connecting the zygomaticofrontal suture of the orbit to the antegonial notch of each side was compared to a normal value of 10 +/- 1.5mm. This approach allowed a clinician to determine whether the skeletal transverse discrepancy was unilateral or bilateral. Grummons outlined another PA analysis with an emphasis on symmetry that has carried merit since its publication (Grummons and Kappeyne van de Coppelo 1987). Like Ricketts analysis, Grummons uses jugal and antegonion to determine skeletal widths.

Unfortunately, standard PA radiographs have many pitfalls and thus have been used largely for research purposes only. The most obvious drawback to making a PA film in addition to the standard lateral cephalometric radiograph is the additional exposure to radiation. Secondly, establishing and reliably locating landmarks using this technique has been difficult in two dimensions due to the superimposition of many anatomical structures from different planes of space (Podesser 2004). The antegonion landmark for instance is not a landmark at all, but rather the most superior point along the curvature of the inferior border of the mandible anterior to the gonial angle, and as such is vulnerable to error. Jugal point is a constructed point based on the intersection of outlines of the maxillary tuberosity and the zygomatic buttress. Like antegonion, this outline produces a curved line with no distinct point, and is subject to a "best guess" identification. It is also highly dependent on the orientation of the head while the radiograph was exposed. Perhaps the biggest limitation of both antegonion and jugal points are their anatomical position; both are located posterior to the dentition and therefore have generated some controversy over the years regarding their utility to orthodontics. Because of these shortcomings, PA cephalometric films have been deemphasized during normal diagnosis and treatment planning. In fact, a survey by the American Association of Orthodontists revealed that only 13% of practicing orthodontists use a PA radiograph regularly (Gottlieb 1990).

Unlike problems occurring in the other two planes of space, where a clinician can begin to make a diagnosis by evaluating facial profile or facial type, there are minimal soft tissue features that are readily available to help with the diagnosis of transverse deficiency (Betts 1995). Instead, clinicians typically rely on clinical exam and maxillomandibular dental relationships to determine transverse discrepancies. Lateral functional shifts, posterior crossbites, a high vaulted palate and excessive buccal corridors are all indications of an underlying skeletal transverse problem. Other skeletal and soft tissue features, such as paranasal hollowing, narrow nasal base, deepened nasolabial folds and hypoplastic zygoma, may provide some information regarding maxillary transverse development, but these techniques have limitations (Menon 2010). Additionally, dental compensations can easily mask an underlying discrepancy between maxillary and mandibular width. In Bjork's implant study of anterior and posterior maxillary widths, he observed that in growing patients the variability of the increase in the bimolar width was twice that of median sutural growth, which indicates that transversal compensatory mechanisms have a great influence on final dental transverse dimensions (Bjork and Skieller 1977). According to Betts, the transverse dimension may be more crucial to stability than either the antero-posterior or vertical dimensions (Betts 1995). Treatment in mature adults can many times be complicated by an undiagnosed transverse discrepancy. Treatment in which dental compensations are maintained or exacerbated can lead to adverse periodontal response, unstable dental camouflage, and poor facial and smile esthetics (Vanarsdall 1999).

In addition to being masked by soft tissue and dental compensations, maxillomandibular transverse discrepancies can often be hidden by skeletal discrepancies in the antero-posterior and vertical dimension. Many authors have described the difference between an absolute and relative transverse discrepancy, whereby absolute discrepancies can be only appreciated after correction to a Class I molar relationship (Banning 1996, Jacobs 1980). Particularly in the case of surgical patients, absolute transverse deficiencies need to be adequately diagnosed and addressed in order to have an ideal and stable result. Betts suggested that surgical correction of any transverse discrepancy greater than 5mm in the skeletally mature patient may be indicated (Betts 1995).

With the introduction of computed tomography (CT) into orthodontics, many researchers have begun to analyze this “forgotten” dimension with renewed interest. Using this three-dimensional technology, clinicians can not only produce traditional lateral or frontal 2D images, but also create a 3D virtual model of the skull (Cevidanes 2006). Arbitrary cuts or slices of any plane along the coronal axis can also help localize transverse discrepancies anywhere along the dental arches in an antero-posterior direction. This new technology has greatly enhanced the clinician’s ability to analyze all three planes of space in the craniofacial complex and develop the needed treatment plan to correct any discrepancies. Use of CT or cone-beam

CT (CBCT) has also eliminated the previous problem of consistency in patient head position during exposure of the radiograph. Imaging software utilizing the dicom files of a CT scan allow a clinician to reorient the head using standardized methods well after the patient has been exposed (Swennen 2006).

Initial clinical use of conventional CT started with Timms in 1980 looking at changes to the maxilla following rapid maxillary expansion (Timms 1980). Podessor, using CT images, developed landmarks comparing maxillary skeletal width to maxillary dentoalveolar width at both the first molar and canine (Podessor 2004). He concluded that CT “represents a reasonable method by which the transverse morphology of the maxillary structures can be described.” Several other authors have followed suit, evaluating the maxillary changes post-orthopedic and surgical expansion, among other things (Loddi 2008, Habersack 2007, Garrett 2008, Garib 2005, Goldenberg 2007).

Reliability of these new technologies has been addressed. Swennen began to present an innovative 3D cephalometric method by conducting a study proving high accuracy and reliability of 3D cephalometric Cartesian reference system based on conventional CT (Swennen 2006). Intra-observer and inter-observer measurement error fell into a range of 0.76-0.88mm for horizontal, vertical and transverse orthogonal measurements. The one exception was the inter-observer error for transverse was slightly higher, measuring 1.26mm. The authors concluded that the 3-D reference system proved accurate and reliable enough to use for both hard and soft tissue analysis. Lagravere, using CBCT instead of conventional CT, reported the reliability for locating many of the traditional 2-D landmarks on 3-D CBCT slices were clinically acceptable (Lagravere 2009). The author found intra-examiner reliability to be greater than 0.97 with 95% confidence interval for x, y, and z coordinates for all landmarks. Inter-examiner, as expected, was slightly less than this but still considered excellent reliability measuring greater than 0.92 with the lone exceptions being the x-coordinates of the orbit and the auditory external meatus.

Holberg reported on the comparison between conventional dental CT and CBCT, which began to be used in the orthodontic field in 1997 (Holberg 2005). While he found that fine detail of dental structures, such as the periodontal ligament, could be better obtained using conventional CT, the newer CBCT system had a number of advantages. The most celebrated advantage of CBCT is the reduced radiation burden to the patient. The process is quicker, cheaper and less technique sensitive and therefore can be accomplished by the orthodontist or orthodontic assistant. Additionally, the CBCT presents superior information of major dental and skeletal structures and shows less metal artifact than conventional CT. Disadvantages of CBCT, in addition to showing less fine detail, include increased susceptibility to movement error, decrease in contrast and an increase in background noise. Despite these negatives, CBCT has become more commonly used among orthodontists and seems to be the technology that will eventually become the gold standard of radiographic evaluation.

With this emergence of new technology comes a need to establish more current concepts on how best to utilize this information. Cho extensively outlined and reviewed standard landmarks from traditional cephalometrics and their significance in three-dimensional cephalometrics (Cho 2009). In his article, Cho proposed an exhaustive analysis using all three planes of space, including transverse comparison of both skeletal and dental maxillary and mandibular components. This analysis does include a comprehensive assessment of the transverse dimension, but as the norms produced were obtained from the measurements of a single adult female subject, further research is needed to reach a level of clinical application.

Research has been done analyzing transverse development of various archforms, grouping subjects based on Angle's classification (Braun 1998, Basaran 2008, Slaj 2010, Uysal 2005). These authors compared Class I and Class III groups using maxillary and mandibular dental widths, using only dental casts and photographs. The research in this area seems to be inconclusive. Braun found the Class III maxillary intermolar widths to be 5.1mm wider than Class I or Class II widths (Braun 1998). These arches also showed a reduced arch depth of 3.3mm, resulting in a more tapering archform in the Class III population. These findings were also found in a study by Basaran supporting the case that maxillary intermolar widths are significantly greater in Class III than either Class I or Class II groups (Basaran 2008). A study by Slaj found Class III patients to have more tapered archform, but these findings were attributed to a reduced intercanine width (Slaj 2010). The result of this study showed no significant difference between Class I and Class III maxillary intermolar width. On the other hand, multiple studies have demonstrated the opposite to be true (Uysal 2005, Chen 2008). Uysal, analyzing the widths of dental casts from 100 Class III arches showed reduced intercanine and intermolar widths of 0.6 and 0.4 mm, respectively, compared with 150 Class I casts. Dentoalveolar widths from the canine and first molar were even more constricted in the Class III group, measuring 2.9 and 1.7mm less than the control, respectively.

Studies of normal skeletal transverse development have been done in a normal Class I population. Findings were that transverse skeletal width develops more rapidly in the mandible than maxilla from the age of 10-18, but these studies also propose that intermolar widths in both arches remain unchanged (Huertas and Ghafari 2001, Bjork and Skieller 1977, Cortella 1997). This suggests that some compensatory mechanism is in place to maintain adequate buccal occlusion despite differences in intermaxillary transverse growth. Other authors have concluded that in normal growing Class I populations, transverse molar movements mirror increases in the width of maxillary basal bone and that the greatest increase is not the intermolar width, but in jugal width (Hesby et al 2006). When it comes to assessing the transverse skeletal development of the maxilla in Class III patients specifically, little research has been done, despite its importance to proper treatment planning. Research based on dental casts give us an idea of possible archform expectations when treating Class III patients, but is this tapered maxillary archform a product of these dental compensations based on deficiencies in the anteroposterior growth or perhaps do they mirror the overall shape of the underlying maxillary basal bone?

In a 2005 study, Franchi and Bacetti stated that “no information is available for the dentoskeletal transverse dimensions in Class III subjects” (Franchi and Baccetti 2005). These investigators looked at growing Class III patients with a mean age of 7 years old and measured their maxillary and mandibular widths using PA cephalometric radiographs. Results of the study indicated that in Class III patients the maxillary width was 4mm narrower than normal, while mandibular widths were normal. These findings suggest that maxillary constriction is a problem that could be diagnosed and corrected early, but regardless of treatment time, is a significant and common diagnosis, one that needs to be accurately assessed and accounted for within defined treatment objectives.

Chen compared longitudinal maxillary skeletal growth in all three planes of space in a Class III population from age 8-14 years (Chen 2006). Using PA cephs, the authors compared maxillary and mandibular widths over time. Their findings indicate that the Class III group had maxillary skeletal constriction compared with the Class I control group for all time points and the intermaxillary ratio based on Jugal point to Antegonion (J-J/Ag-Ag) decreased more rapidly from age 8 to 14 for the Class III group. By age 14, maxillary/mandibular width percentage of Class III subjects was just 67% compared with 75% in Class I subjects.

In another article, Chen and colleagues evaluated not only the skeletal maxillary and mandibular widths but included intermolar widths at the first molars (Chen 2008). Results were similar. The Class III group showed statistically significant reduced intermolar width at the first molar compared with Class I at all ages. The ratio of upper to lower intermolar ratio decreased in Class III patients from age 10 to 14 years and remained the same in Class I patients. These results contradict the previous discussed work by Braun and Basaran. Skeletal findings in this study were similar to the author's previous article with Class III patients having on average a more constricted maxillary width (J-J).

No other current studies appear in the literature regarding maxillary widths of Class III patients and no research appears in the literature regarding Class III maxillary widths of non-growing patients at all. There also appears to be no literature attempting to describe the relationship between the width of the anterior and posterior maxilla in a Class III population. Based on the current literature, it seems that these patients show a more tapered dental archform, but research has not been forthcoming as to whether this tapered form can also be seen in the maxillary basal bone. Additionally, no studies have attempted to use CBCT to accurately assess the skeletal widths of this population specifically.

The first goal of this study was to propose skeletal landmarks in both the anterior and posterior portions of the maxilla and locate these landmarks using CBCT to obtain average maxillary skeletal widths in a group of non-growing Class I patients with normal transverse widths. In the second part of this project, the objective was to compare this information to a group of non-growing Class III patients that have deficient maxillary growth in an antero-posterior dimension. In comparing the average maxillary widths and the subsequent anterior-to-posterior ratios of these two populations, we may conclude whether a maxilla deficient in the AP plane of space may be more likely to also be deficient in the transverse plane. This information could be subsequently used for proper diagnosis of the hypoplastic maxilla with three-dimensions in mind.

II. OBJECTIVES

A. Overall Objective

The overall objective of this study was to determine if a group of patients known to be deficient in maxillary antero-posterior growth would also be predisposed to growth deficiency in the transverse dimension. The goal of this study was to first identify reliable anterior and posterior maxillary landmarks in a Class I population with no transverse discrepancies and using these landmarks determine mean widths in the maxilla. The second objective of this study was to use this normalized data to determine if a population with deficient antero-posterior maxillary growth may also be expected to have deficient transverse maxillary growth and whether the deficiency will be localized to the anterior and/or posterior portion of the maxilla.

B. Specific Hypotheses

It is hypothesized that if hypoplasia of the maxilla occurs in the antero-posterior plane, it will also occur in the transverse dimension.

III. MATERIALS AND METHODS

A. Experimental Design

This retrospective study included patients who were examined at the Tri-Service Orthodontic Training Program with pretreatment CBCTs on file, taken on iCAT® Classic and Platinum machines (Imaging Sciences International, Hatfield, PA) using 0.3mm voxel size. After a search through the program's patient database, the first 49 Class I subjects to meet the following inclusion criteria were selected for the initial part of the research:

1. Females at least 14 years old and males at least 16 years old
2. No previous orthodontic treatment
3. Skeletal Class I with an A point-Nasion-B point (ANB) angle between 0-4 degrees with bilateral Class I molars and canines
4. No crossbites or transverse dental compensations (as diagnosed by the principle investigator)
5. Have fully erupted canines (no impactions) and no severe crowding (less than 8mm)
6. Have a normal face height with sella-nasion to mandibular plane angle (SN-MP) between 28 to 38 degrees

A Class III patient population was located using the same preexisting database of patients of the Tri-Service Orthodontic Training Program. All of these patients, like the Class I populations, had an initial examination that included a pretreatment CBCT, taken on iCAT® Classic and Platinum machines (Imaging Sciences

International, Hatfield, PA). The first 30 Class III subjects to meet the following inclusion criteria were identified:

1. Females at least 14 years old and males at least 16 years old
2. No previous orthodontic treatment
3. Skeletal Class III due to maxillary deficiency defined as a ANB angle less than 0 degrees and an Sella-Nasion-A point (SNA) angle less than 82 degrees
4. Have fully erupted canines (no impactions) and no severe crowding (less than 8mm)
5. Have a normal face height with SN-MP angle between 28 to 38 degrees

No exclusion criteria were established to control for race in either group.

Of the 49 Class I patients, 22 were male and the average age was 25 years 2 months old (range 14-50 years). The average ANB angle was 2.4 degrees and the average SNA angle was 82.6 degrees. The Class III group consisted of 30 patients, including 20 males and had an average age of 24 years 7 months old (range 14-44 years). The average ANB angle was -2.6 degrees and the average SNA angle was 79.8 degrees. (See Appendix A)

As a matter of selecting landmarks for identification and analysis, Goldenberg wrote "in the interest of reproducibility of results, the anatomic landmarks and structures must be easily recognizable by all professionals." (Goldenberg 2007) In addition to this parameter, landmarks were selected by their potential consistency and accuracy. Lagravere, in his study of reliability of CBCT landmarks, found excellent reliability for upper root apices and the point he termed Ectomolare (EKM), defined as the point on the outer surface of alveolar ridge corresponding to first molar mesio-buccal apex projection to the bone (Lagravere 2007). Additionally, he proposed Piriform (Pf) as another reliable landmark, defined as the point located on the outermost of the nasal wall in the widest width of the nasal orifice. Other authors have also chosen to use maxillary root apices and a point similar to EKM in their analysis (Cho 2009, Podessor 2004). The greater palatine foramina (GPF) has been used to determine width changes post-surgically assisted maxillary expansion by Goldenberg using conventional CT scans (Goldenberg 2007). Casperson used both Piriform aperture width (Pf) and the width between infraorbital foramina as anterior maxillary landmarks in his study comparing infraorbital canal inclination to maxillary width (Casperson 2009).

For this study, six landmarks were chosen and characterized as to whether they are anteriorly or posteriorly positioned with three landmarks in each of these groups. Anterior skeletal landmarks identified are as follows: 1) Infraorbital foramina (IF), 2) Piriform or nasal orifice at the widest point (Pf) and 3) Canine root apices (CRA). Posterior skeletal landmarks identified are: 1) Buccal Point or intersection of maxillary tuberosity and zygomatic buttress at level of first molar mesiobuccal root (BP), 2) Greater palatine foramina (GPF) and 3) Maxillary first molar palatal root apices (MRA) (Figures 1-6). The six landmarks were identified solely by the principal investigator using the Dolphin Imaging 10.5 3D software application (Dolphin Imaging and Management, Chatsworth, CA). All landmarks were marked bilaterally and widths measured directly on coronal slices cut from the dicom files of each patient's preexisting CBCT to determine maxillary widths. This process was repeated during three time intervals for all patients.

Figure 1

Anterior Landmark: Canine root apices (CRA)

Figure 2

Anterior Landmark: Piriform or nasal orifice at the widest point (Pf)

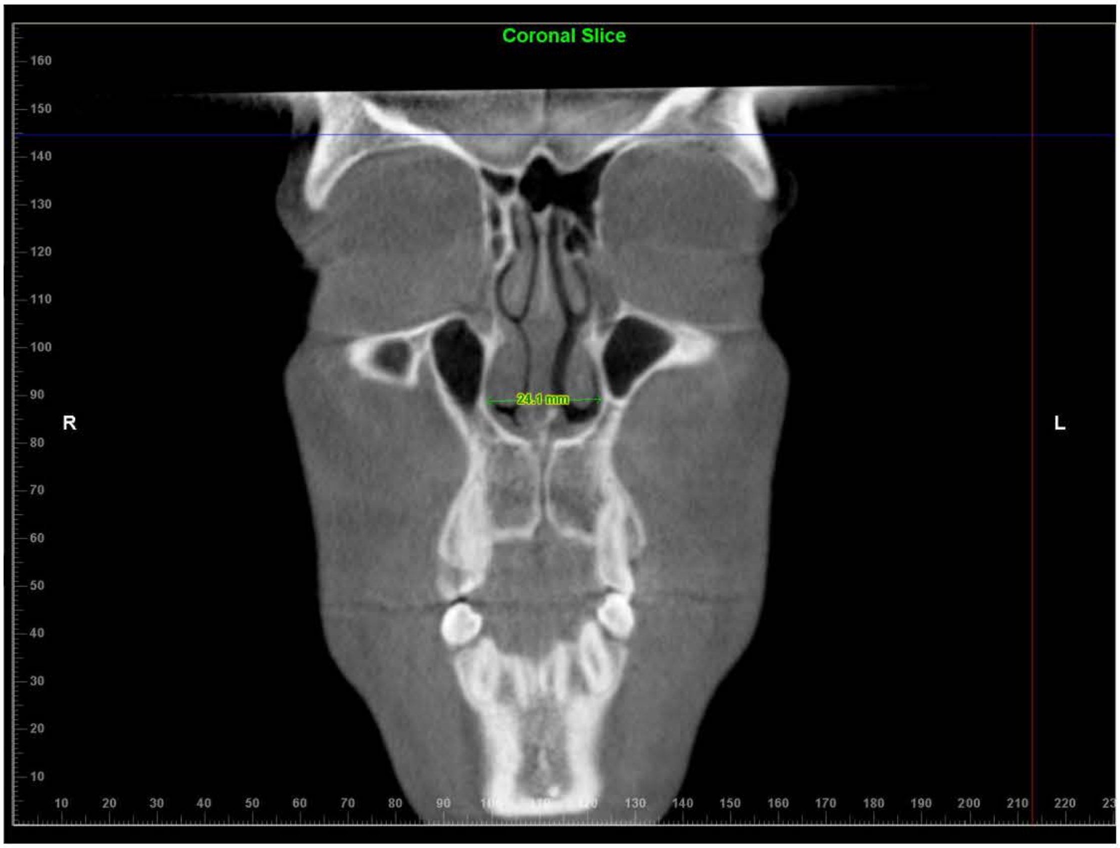


Figure 3

Anterior Landmark: Infraorbital foramina (IF)

Figure 4

Posterior Landmark: Maxillary first molar palatal root apices (MRA)

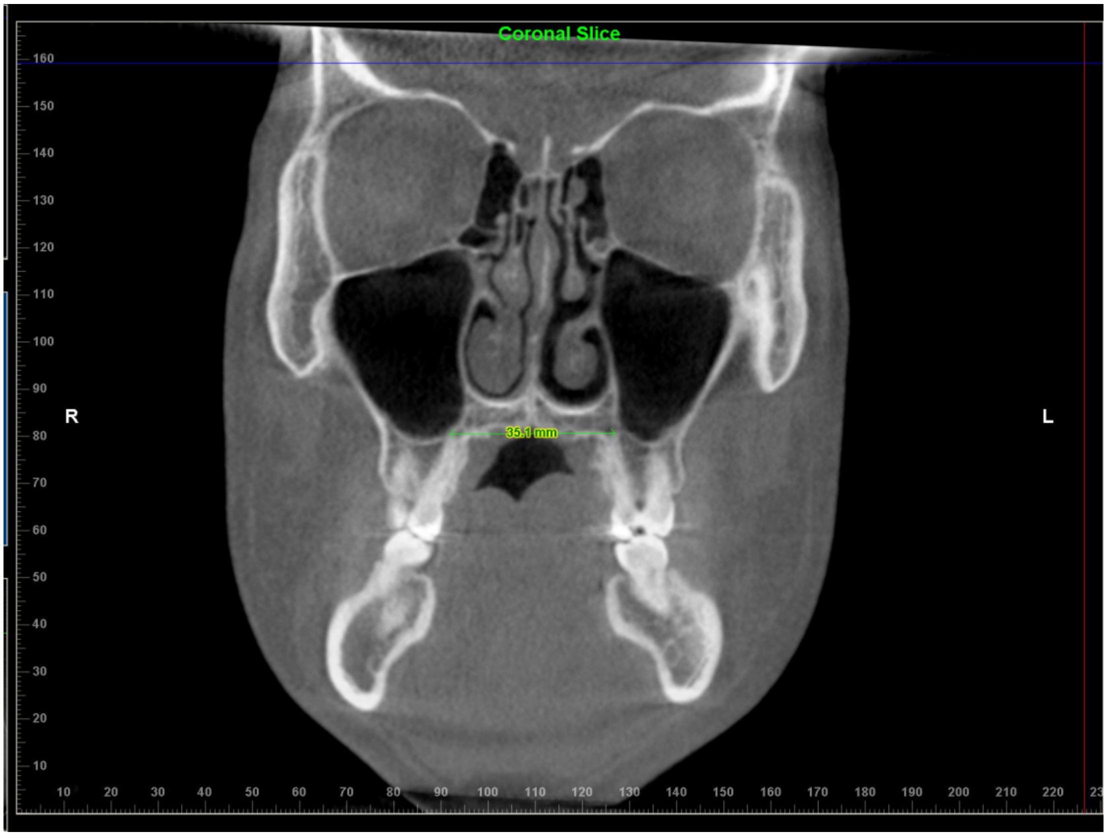


Figure 5

Posterior Landmark: Greater palatine foramina (GPF)

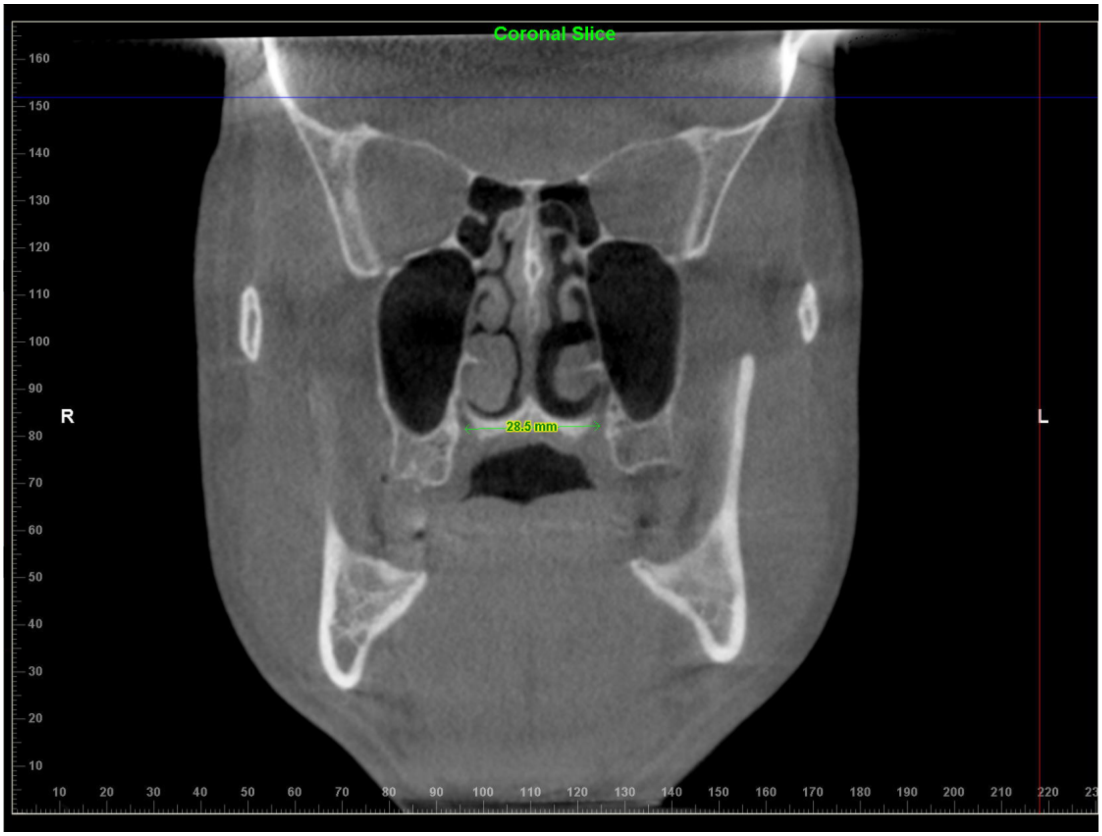


Figure 6

Posterior Landmark: Buccal Point or intersection of maxillary tuberosity and zygomatic buttress at level of first molar mesiobuccal root (BP)

B. Statistical Management of Data

Six landmarks (three in the anterior maxilla and three in the posterior maxilla) were identified and measured at three different time points using coronal slices from the CBCTs of the first twenty Class I patients. Mean averages and standard deviations were determined from these widths. Intra-rater reliability was calculated using the average standard deviation derived from the three linear measurements made from each individual. One of the anterior landmarks and one of the posterior landmarks were eliminated from the remainder of the study based on these results.

The remaining four landmarks were measured in the same pattern as before (three time intervals) for the remaining Class I population and for the entire Class III population. Averages and standard deviations were obtained for each landmark in both populations and compared using Student's t test. Ratios were constructed using each of the combinations of anterior-to-posterior landmarks for each individual patient in both populations. These individual ratios were averaged for both populations and compared again using Student's t test. Values of $p < 0.05$ were considered statistically significant.

IV. RESULTS

A pilot study, consisting of the first twenty Class I patients and all six of the landmarks identified as potential sites for maxillary width measurements, showed that the intra-rater reliability of all landmarks was very good (Table I). All landmarks were located at three different times by one examiner. Only Buccal Point (BP), with an average standard deviation of 0.76mm, proved to have a greater standard deviation than 0.5mm.

Following the results of the pilot study, BP was eliminated as a posterior landmark because it proved to be the most difficult to reliably locate. This was largely due to the convexity with which the maxilla ascends and intersects the zygoma, a similar problem as to finding the location of jugal point using the Ricketts analysis (Ricketts 1981). It was difficult to consistently define where along this curvature the alveolar housing ended and the maxillary bone proper began. Artificially electing to identify BP directly at the level of the mesiobuccal root apices, as suggested by Lagrevere, or a millimeter distance superior to the apex helped to provide some consistency (Lagrevere 2009). In some cases, however, the maxillary bony housing is already ascending laterally at the height of the root apices and therefore using apices as an indicator to determine BP can be unreliable.

The anterior landmarks piriform or nasal orifice at the widest point (Pf) and infraorbital foramina (IF) proved to be very similar in intra-rater reliability and both were generally located at a similar height toward the superior border of the maxillary bone. Landmark Pf was eliminated for the remainder of the study, because it was

Table I. Accuracy Statistics (in mm) of Six Landmarks Measured From Initial Twenty Class I Group

	Class I Pilot Group (n=20)			
Location	Variables	Mean	SD	Accuracy
ANTERIOR	IF-IF	50.52	4.25	0.48
	Pf-Pf	24.86	2.23	0.47
	CRA-CRA	27.47	2.78	0.44
POSTERIOR	BP-BP	60.28	3.44	0.76
	GPF-GPF	29.18	2.25	0.32
	MRA-MRA	33.65	4.13	0.54

SD indicates standard deviation;
Accuracy= average SD per individual for three time points

thought that this point might prove more difficult to consistently locate among multiple raters since this landmark is more subjective, as it falls, not at the opening of a specific foramen, but along a bony wall. As such, multiple locations in both a superior-inferior and anterior-posterior direction could be considered the Piriform orifice.

For the remainder of the study, four landmarks were used, canine root apices (CRA) and IF in the anterior maxilla and palatal root apices of first molars (MRA) and the greater palatine foramen (GPF) in the posterior maxilla. Statistical differences existed between Class I and Class III populations for two of the four landmarks, CRA and GPF (Table II). Class III patients had an average CRA width 1.6mm narrower and an average GPF width that was 1.8mm wider than that of the Class I population. No statistical differences were noted for either IF or MRA.

Using these two anterior and two posterior ratios, four anterior-to-posterior (A-P) ratios were constructed. Three out of the four A-P ratios of transverse widths showed statistical significance when comparing the two groups (Table III). There was a central tendency among all four ratios produced with the Class III group consistently exhibited a reduced ratio compared with the Class I group, indicating either a reduced anterior width or an increased posterior width or perhaps a combination of the two (Figure 7). Landmarks CRA-GPF showed the greatest significant difference ($p<0.001$), measuring 0.95 +/- 0.10 in the Class I group compared to 0.84 +/- 0.11 in the Class III group. Additionally, the ratio IF:GPF showed high significance ($p<0.001$) with the Class I group measuring 1.73 +/- 0.13

Table II. Descriptive Statistics and Statistical Comparisons of Linear Transverse Maxillary Skeletal Width Measurements (in mm) in Class I and Class III Groups

	Class I Group (n=49)				Class III Group (n=30)				Class I vs. Class III
Variables	Mean	SD	Min	Max	Mean	SD	Min	Max	
IF-IF	50.5	4.2	41.7	59.7	50.0	4.1	42.4	56.4	NS
CRA-CRA	27.6	2.7	20.6	34.4	26.0	3.4	19.9	32.0	*
GPF-GPF	29.2	2.8	22.8	34.5	31.0	2.9	26.7	37.4	**
MRA-MRA	33.4	4.0	25.4	45.4	33.6	3.6	28.2	42.1	NS

SD indicates standard deviation; Min, minimum; Max, maximum; NS, not significant

* $P < .05$

** $P < .01$

Table III. Descriptive Statistics and Statistical Comparisons of Anterior-to-Posterior Transverse Ratios of Maxillary Skeletal Width Measurements in Class I and Class III Groups

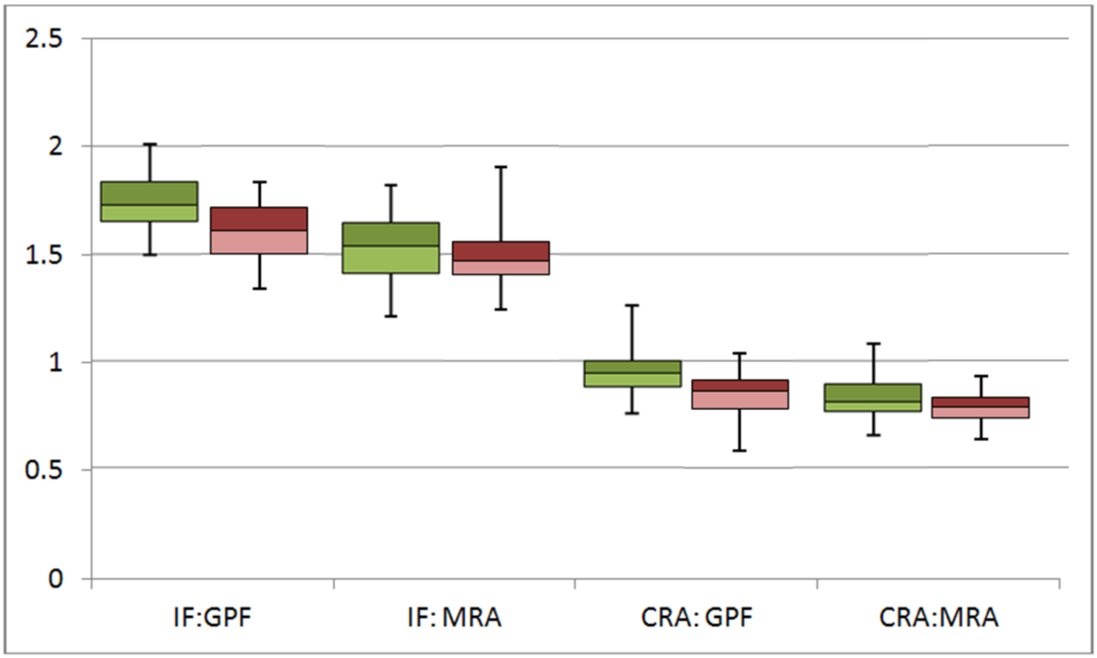
	Class I Group (n=49)				Class III Group (n=30)				Class I vs. Class III
Ratio	Mean	SD	Min	Max	Mean	SD	Min	Max	
IF:GPF	1.734	0.125	1.497	2.012	1.621	0.151	1.335	2.009	***
IF:MRA	1.527	0.151	1.204	1.816	1.496	0.139	1.236	1.902	NS
CRA:GPF	0.950	0.095	0.757	1.257	0.844	0.114	0.584	1.034	***
CRA:MRA	0.836	0.097	0.655	1.081	0.775	0.077	0.631	0.926	*

SD indicates standard deviation; Min, minimum; Max, maximum; NS, not significant

* P < .05

*** P < .001

Figure 7
Quartile Comparison of A-P ratios based on transverse measurements of four landmarks for Class I (in green) and Class III (in red) groups



Median represented by line within box; second quartile values, box below median; third quartile, box above median; minimum, low whiskers; maximum, high whiskers.

and the Class III group measuring 1.62 +/- 0.15. CRA-MRA showed a slightly smaller but still significant difference ($p<0.05$), 0.84 +/- 0.10 for Class I and 0.76 +/- 0.08 for Class III. These results all indicate that Class III patients have a more tapered maxillary skeletal base than Class I patients resulting from a wider posterior and/or a narrower anterior. IF-MRA was the only ratio not to show statistical significance, but as with the other ratios, the Class III group displayed a reduced value.

V. DISCUSSION

Ideally, a study such as this one would be able to determine if any of the chosen skeletal landmarks can reliably produce a linear width that proves to be a useful indicator for comparison to what we determine to be a normal range of maxillary width, similar to the work done by Ricketts using conventional PA cephalometrics (Ricketts 1981). By comparing a normalized linear value to subsequent patients in a clinical setting, we could get an assessment of maxillary transverse sufficiency with a simple comparison. Individual anatomical variation based on factors like head size and face type variability often preclude clinicians from reaching definite conclusions in this manner. Rather than using linear millimeter measurements, angles and ratios are used instead to determine normal values for diagnostic purposes. The objective for this study was that conclusions be reached not only for overall transverse maxillary widths of both groups, but to more specifically define where differences occurred, particularly if a difference existed between Class I and Class III in the anterior or posterior maxilla or both. Subsequently, normalized anterior-to-posterior ratios of skeletal widths were constructed to analyze this with the potential that perhaps one or more of these ratios may prove to be a useful tool for clinical diagnoses.

Results from the individual landmark analysis were not entirely expected. While no significant differences existed between the infraorbital foramina (IF) width in the anterior and the first molar palatal root apices (MRA) in the posterior, differences were found in the other two points. These two significant findings seem to contradict one another. The distances between canine root apices (CRA) were more constricted in the Class III population by more than 1.5mm. However, in the posterior maxilla, distances between the two greater palatine foramina (GPF) were wider in the Class III population by close to 2mm. Though it is difficult to make conclusions based on the linear widths, the values obtained suggest that the Class III population actually had a greater transverse development in the posterior maxilla and greater constriction in the anterior region compared to a normal population. When expressed as a ratio using the average widths of these anterior and posterior landmarks, the difference is highly significant ($p<0.001$) and clearly depicts the hypoplastic Class III maxilla as much more V-shaped, or tapered, than a maxilla with normal sagittal growth. The Class I group had a CRA:GPF ratio of 0.950, while the Class III group averaged 0.844. Likewise, A-P ratios using IF-GPF showed a highly significant difference between Class I and Class III, 1.73 and 1.62, respectively. In fact, all four A-P constructed ratios of Class III patients were reduced compared with Class I patients, including CRA-MRA ratios, which showed a weaker statistical significance ($p<0.05$), and IF:MRA, which was the only ratio not to show statistical significance. These data all confirm that the Class III group exhibited a greater narrowing of the maxilla from posterior to anterior.

Similar findings have been seen in the literature based strictly on the maxillary dental archform, though conflicting data exists for this as well. Most dental archform studies agree that a constriction is present in the maxillary anterior of a Class III arch, but the data is split on whether the posterior dental width will show a constriction or widening (Braun 1998, Basaran 2008, Slaj 2010, Uysal 2005, Chen 2008). Of the studies that have characterized the maxillary skeletal widths, the consensus seems to indicate that a maxillary transverse constriction is commonly present in Class III patients compared with Class I patients (Franchi and Bacetti 2005, Chen 2008). Both of these studies compared widths between bilateral Jugal points using PA cephalograms. Jugal point, defined as the intersection of the outline of the tuberosity of the maxilla and the zygomatic buttress, is located posterior to the maxillary dentition, similar to greater palatine foramina, which was used in this study. Franchi and Bacetti found a 3.8mm maxillary constriction in a group of growing Class III patients with an average age of 7 years old, while data from Chen et al reported a 1.73mm maxillary constriction at age 10 that increased to 3.37mm by age 14. It is important to note that no studies to date have analyzed the maxillary transverse widths of non-growing Class III patients. Additionally, because these and other previous studies have been limited to PA cephalograms, which do not allow for differential assessment of anterior vs. posterior landmarks, and dental casts, which do not provide information pertaining to skeletal measurements, it is difficult to make a direct comparison between this study and others.

It should be pointed out that this study too has limitations. No second evaluator was used to verify the linear widths making the determination of inter-rater reliability impossible. Previous studies of this type have shown, however, that inter-rater reliability, while not as strong as intra-rater reliability, has fallen well within a range considered acceptable (Goldenberg 2007, Lagrevere 2009). The intra-rater reliability reported here showed good reproducibility of measurements and therefore it was concluded that little information would be gained from an additional evaluator.

Secondly, this study aims to determine growth in patients with hypoplasia of the maxilla. In order to do that, inclusion criteria were established to limit our Class III group to only patients with this characteristic. Because Class III patients make up only a small percentage of the general population and the fact that much of this population is Class III not because of maxillary hypoplasia, but rather mandibular hyperplasia, the SNA angle, which was used to establish the diagnosis of maxillary A-P hypoplasia, was set at less than 82 degrees. In fact, the normal range for SNA in a Caucasian population is 82 degrees +/- 2 degrees, so any of our participants with an SNA between 80-82 degrees could be considered to have normal maxillary A-P growth (Proffit 2007). Only eleven of the 30 patients in our Class III group had an SNA angle of less than 80 degrees. However, it should be noted that there was a significant difference between the Class I and Class III groups in SNA angle (Appendix A). The Class I group SNA mean was 82.6 degrees while that of the Class III group was below the lower limit of normal at 79.8 degrees. While that difference indicates the Class I population indeed does have more maxillary A-P growth than the Class III population, in fact the true picture is not as clear as that, since SNA angles can be affected not only by the maxilla, but also the A-P location of nasion and the steepness of the cranial vault. The difference in ANB angles between the two groups, which are used to relate the maxilla and mandible in A-P projection and confirm the diagnosis of skeletal class, were also significant with the

Class I group measuring 2.4 degrees and the Class III group measuring -2.7 degrees. There was no attempt to establish exclusion criteria based on racial differences and therefore the study groups were composed of individuals of different racial backgrounds.

Lastly, no external references were used to normalize the maxillary skeletal widths. More data obtained from sources such as facial width, mandibular skeletal width or intermaxillary dental widths would have proved beneficial in determining if the significant differences found in the linear width measurements were a product of actual Class III growth patterns or simply individual variability. Measurements of maxillary molar angulation or intermolar width at the occlusal and gingival level would have allowed for the assessment of dental compensation present in each of the two populations. Despite this omission of information, by using ratios determined from these linear measurements instead of the widths themselves, any differences noted should have fallen in an insignificant range if these two groups were truly statistically similar. Instead, our data clearly shows that the maxillary skeletal form in these two groups is not the same based on these chosen landmarks. Since our results are similar to others concerning the width of the anterior maxilla, the conflict of results may lie in the posterior widths. Therefore one of the questions that arise is whether the greater palatine foramina are useful landmarks to determine posterior maxillary width. Based on previous studies, use of foramina seems reasonable for longitudinal growth assessments in one individual, but this does not necessarily account for the location of these foramina found among multiple individuals (Bjork and Skieller 1977). Sejrsen showed that maxillary sagittal growth occurs anterior to the greater palatine foramina, but growth in width between these foramina seems to continue into adult life (Sejrsen 1996). Goldenberg used GPF to determine maxillary width, but his study involved assessing the skeletal effects of surgically assisted maxillary expansion and as such did not involve comparing these widths between individuals, but rather the difference between bilateral GPF width on pre- and post-treatment CT scans of the same individual (Goldenberg 2007). Sujatha evaluated the position of the greater palatine foramina on seventy-one adult skulls (Sujatha 2005). The difference in the distance of the foramina from mid-sagittal suture and posterior palatal border was found to be statistically insignificant, showing that some consistency can be found among multiple individuals. In hindsight, perhaps by retaining BP as a landmark or adding additional posterior landmarks further analysis of the posterior maxilla could have been assessed. Another way to validate the greater palatine foramina as legitimate landmarks for transverse studies would be to compare these widths between two groups of Class I subjects, one with adequate maxillary transverse dimension and another with maxillary transverse deficiency. As it stands, until further studies are undertaken, we are left to wonder if the data presented can be used as an indication of true posterior maxillary transverse development in the Class III patient or merely the width between locations of the bilateral greater palatine foramina and nothing more.

Further analysis of the data was completed, due to the unexpectedness of the results, to determine if the study populations were truly matched. A potential significant difference between the two groups was the male:female ratio. In the Class I group 55% of the patients were female, whereas the Class III group was composed of only 33% females. Males tend to show an increase in size in the transverse dimension compared with female beginning at age 11-12 years (Cortella 1997). Therefore, this discrepancy between the two non-growing groups could potentially explain the differences noted in width, particularly the increased width between the GPF in Class III. Removing all females from the study left 22 male participants in the Class I group and 20 males in the Class III group. Age, another complicating factor, showed no significant difference among the remaining all-male study groups. In accordance with previous mentioned literature, this new subset population of male-only patients showed an increase in the overall width of all four landmarks in both groups when compared to the original groups comprised of males and females. Within this new data, significant differences in linear widths were only seen for landmark CRA, though the trends remained the same (Table IV). This subset of participants showed the same pattern with respect to A-P ratios in the comparison of Class I to Class III, with the latter group have a more tapered skeletal form represented by lower A-P ratios (Table V). Significant differences were noted for the IF:GPF, CRA:GPF and CRA:MRA ratios, though due to the reduced population size these differences carried less statistical significance than seen with the entire populations. Compared with data for both sexes combined, male participants showed a slight increase in all four A-P ratios in both test groups suggesting that males overall have a slightly less tapered maxillary skeletal form than females. These differences, however, were not statistically significant.

Table IV. Descriptive Statistics and Statistical Comparisons of Linear Transverse Maxillary Skeletal Width Measurements (in mm) in Class I and Class III Males only

	Class I Males (n=22)				Class III Males (n=20)				Class I vs. Class III
Variables	Mean	SD	Min	Max	Mean	SD	Min	Max	
IF-IF	53.3	3.5	45.6	59.7	51.4	3.7	45.7	56.4	NS
CRA-CRA	29.5	2.1	26.4	34.4	27.2	3.1	19.9	32.0	**
GPF-GPF	30.6	2.2	26.5	34.0	31.8	2.9	27.1	37.4	NS
MRA-MRA	34.8	4.2	28.1	45.4	34.3	4.1	28.2	42.1	NS

SD indicates standard deviation; Min, minimum; Max, maximum; NS, not significant

** P < .01

Table V. Descriptive Statistics and Statistical Comparisons of Anterior-to-Posterior Transverse Ratios of Maxillary Skeletal Width Measurements in Class I and Class III Males only

	Class I Group (n=22)				Class III Group (n=20)				Class I vs. Class III
Ratio	Mean	SD	Min	Max	Mean	SD	Min	Max	
IF:GPF	1.748	0.126	1.497	2.000	1.629	0.153	1.371	2.009	**
IF:MRA	1.544	0.159	1.228	1.751	1.509	0.144	1.341	1.902	NS
CRA:GPF	0.967	0.080	0.824	1.116	0.863	0.114	0.584	1.034	**
CRA:MRA	0.855	0.103	0.655	1.081	0.796	0.070	0.679	0.926	*

SD indicates standard deviation; Min, minimum; Max, maximum; NS, not significant

* P < .05

** P < .01

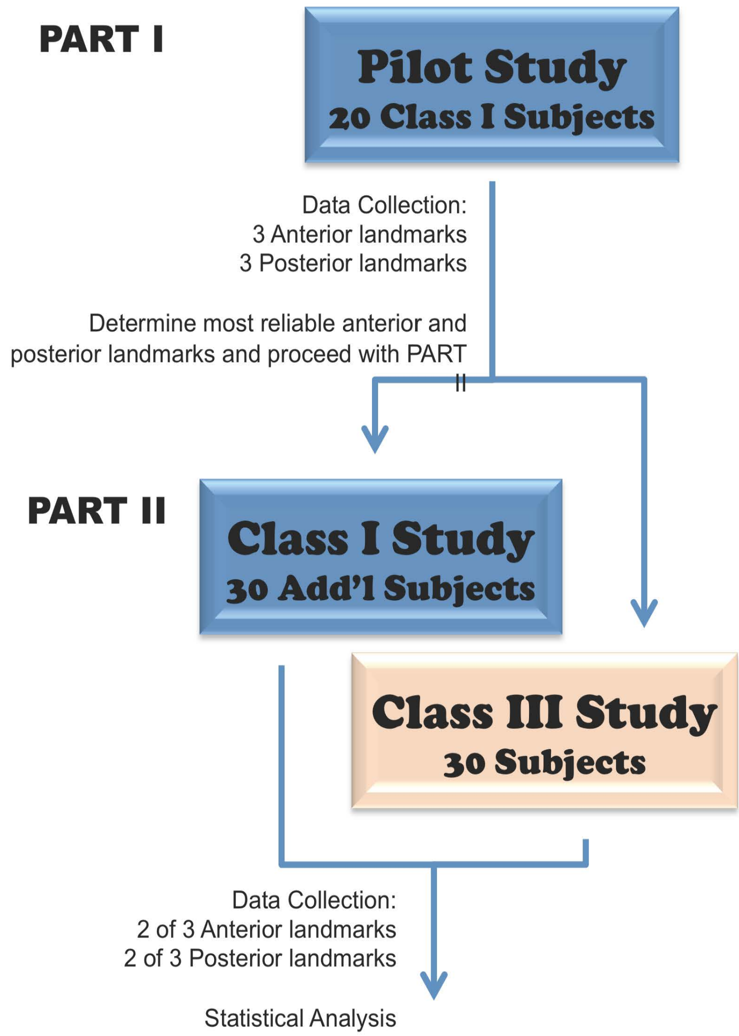
One of the objectives of this study was to determine if any combination of transverse landmark measurements would produce an A-P ratio that would provide beneficial diagnostic information for future patients. From this study, the two most promising ratios were IF:GPF and CRA:GPF, which both showed a highly significant difference between the Class I and Class III groups. Unfortunately, due to the overall variance between individuals, this difference was probably not sufficient enough to provide clinicians with a great marker with which to compare future patients. The ratios constructed from the purely skeletal-based landmarks infraorbital and greater palatine foramina varied from 1.50-2.01 and 1.34-2.01 for the Class I and III patients, respectively. While those using maxillary canine apices and greater palatine foramina ranged from 0.76-1.26 and 0.58-1.03 for the Class I and III patients, respectively. Overall, the Class III ratio means for both IF:GPF and CRA:GPF were almost exactly one standard deviation less than that of the control Class I group with many of the Class III ratios falling into the normal range. Based on this information, it seems as of yet no statistical analysis can be applied as a screening tool to diagnose maxillary transverse deficiency or to determine if that deficiency occurs in the anterior or posterior maxilla. It is important to note the overall tendency for Class III non-growing patients to exhibit a tapered maxilla with a narrowed anterior dimension compared with a normal population. This information has many treatment planning implications whether a surgical or non-surgical approach is decided.

Further studies need to be conducted with additional landmarks and involve both the maxillary and mandibular skeletal bases as well as anterior and posterior dental structures in both arches using CBCT. This additional data would provide a greater overall picture of the likelihood of maxillomandibular discrepancies in the transverse dimension in both Class I and Class III patients and differentiate where in the dental arches these discrepancies are most likely to occur.

VI. CONCLUSION

1. Bilateral transverse linear widths using maxillary canine root apices showed that the Class III group had a narrower dimension in the anterior maxilla compared to the Class I group, while widths between greater palatine foramina indicated that the Class I group had a narrower dimension in the posterior maxilla.
2. Anterior-to-Posterior ratios using transverse widths measured between various bilateral maxillary skeletal landmarks showed that patients with maxillary AP hypoplasia (Class III) showed a greater tapering of the maxilla from posterior to anterior.
3. Transverse widths determined using the six landmarks located on CBCT coronal slices and presented in this study showed good intra-rater reliability and would be acceptable for further studies.
4. Though easily and accurately located using CBCT images, it is unclear whether the greater palatine foramina prove to be reasonable landmarks to use to determine posterior maxillary skeletal width.

Appendix A. Study algorithm including Inclusion Criterion for both Class I and Class III groups



Class I Inclusion Criteria:

1. Females over age 14 years old and males over age 16 years old
2. No previous orthodontic treatment
3. Skeletal Class I (ANB = 0-4 degrees) with bilateral Class I molars and canines
4. No crossbites or transverse dental compensations
5. Have fully erupted canines (no impactions) and no severe crowding (less than 8mm)
6. Have a normal face height with sella-nasion to mandibular plane value (SN-MP) between 28 to 38 degrees

Retrospective study with patients selected from TORP database of CBCT volumetric images dated 2007 to present. Patients will be de-identified prior to data collection.

Class III Inclusion Criteria:

1. Females over age 14 years old and males over age 16 years old
2. No previous orthodontic treatment
3. Skeletal Class III due to maxillary deficiency (ANB < 0 degrees, SNA < 82 degrees)
4. Have fully erupted canines (no impactions) and no severe crowding (less than 8mm)
5. Have a normal face height with sella-nasion to mandibular plane value (SN-MP) between 28 to 38 degrees

Appendix B. Statistical Comparisons of inclusive characteristics in Class I and Class III Groups

	Class I Group (n=49)				Class III Group (n=30)				Class I vs. Class III
Variables	Mean	SD	Min	Max	Mean	SD	Min	Max	
Age	25.2	9.1	14.0	50.3	24.5	8.7	14.0	43.9	NS
SNA	82.6	3.0	76.5	88.3	79.8	1.9	75.6	82.0	***
ANB	2.4	1.1	0.2	4.0	-2.7	2.7	-12.6	-0.1	***

SD indicates standard deviation; Min, minimum; Max, maximum; NS, not significant

SNA= Sella-Nasion-A point angle; ANB= A point-Nasion-B point angle

*** P < .0001

Appendix C: Class I Pilot Study (Six Landmarks, n=20), Raw Data

		Timepoint 1	Timepoint 2	Timepoint 3	Mean	SD
MAX 1-01	IF-IF	44.3	44.7	43.6	44.2	0.556776
	Pf-Pf	21.7	21.3	21	21.333333	0.351188
	CRA-CRA	25.3	26.6	26.5	26.133333	0.723418
	BP-BP	52.9	51.5	51.6	52	0.781025
	GPF-GPF	25.6	26.1	26.4	26.033333	0.404145
	MRA-MRA	26.5	26.9	25.4	26.266667	0.776745
MAX 1-02	IF-IF	44.6	45.9	46.3	45.6	0.888819
	Pf-Pf	25.4	25.6	25.1	25.366667	0.251661
	CRA-CRA	27	27.1	27	27.033333	0.057735
	BP-BP	59.7	55.7	57.2	57.533333	2.020726
	GPF-GPF	28.7	28.4	28.5	28.533333	0.152753
	MRA-MRA	32.6	30.5	31.3	31.466667	1.059874
MAX 1-03	IF-IF	50.7	50.2	51.6	50.833333	0.70946
	Pf-Pf	28.9	27.4	27.3	27.866667	0.896289
	CRA-CRA	25	27.2	26.3	26.166667	1.106044
	BP-BP	63.3	60.3	62.7	62.1	1.587451
	GPF-GPF	29.3	29.6	30.3	29.733333	0.51316
	MRA-MRA	33	32.8	33	32.933333	0.11547
MAX 1-04	IF-IF	47.8	47.8	46.8	47.466667	0.57735
	Pf-Pf	24.2	24.2	23.5	23.966667	0.404145
	CRA-CRA	22.9	23.5	23.5	23.3	0.34641
	BP-BP	57.2	56.9	57.2	57.1	0.173205
	GPF-GPF	26.5	26.6	26.2	26.433333	0.208167
	MRA-MRA	28.5	28.3	28.4	28.4	0.1
MAX 1-05	IF-IF	54.5	54.1	52.8	53.8	0.888819
	Pf-Pf	26.6	26.4	26.8	26.6	0.2
	CRA-CRA	34.9	34.2	34.2	34.433333	0.404145
	BP-BP	66.4	65.7	65.2	65.766667	0.602771
	GPF-GPF	32	31	31.2	31.4	0.52915
	MRA-MRA	42	41.7	41.9	41.866667	0.152753
MAX 1-06	IF-IF	59.5	59.6	60	59.7	0.264575
	Pf-Pf	22.7	23	23	22.9	0.173205

	CRA-CRA	28.5	27.9	29	28.466667	0.550757
	BP-BP	63.6	60.6	60.9	61.7	1.652271
	GPF-GPF	30.8	31	31.2	31	0.2
	MRA-MRA	34.2	36.1	37	35.766667	1.429452
MAX 1-07	IF-IF	45.4	45.2	44.5	45.033333	0.472582
	Pf-Pf	22.2	22.3	21.7	22.066667	0.321455
	CRA-CRA	25.2	26	25	25.4	0.52915
	BP-BP	58.8	58.1	58.4	58.433333	0.351188
	GPF-GPF	26.6	26.2	26.2	26.333333	0.23094
	MRA-MRA	32.2	32.8	31.8	32.266667	0.503322
MAX 1-08	IF-IF	52.2	52.5	52.2	52.3	0.173205
	Pf-Pf	25.4	24	25.2	24.866667	0.757188
	CRA-CRA	27.4	27.8	27.6	27.6	0.2
	BP-BP	63.7	63.9	63.7	63.766667	0.11547
	GPF-GPF	31	30.9	30.9	30.933333	0.057735
	MRA-MRA	32.5	32.3	33.8	32.866667	0.814453
MAX 1-09	IF-IF	48.2	47.8	48.8	48.266667	0.503322
	Pf-Pf	26.1	25.2	26	25.766667	0.493288
	CRA-CRA	30.2	28.3	28.9	29.133333	0.971253
	BP-BP	62.4	63.4	63	62.933333	0.503322
	GPF-GPF	28.9	28.7	29.3	28.966667	0.305505
	MRA-MRA	31.3	31.9	32.5	31.9	0.6
MAX 1-10	IF-IF	48.8	48.6	48.4	48.6	0.2
	Pf-Pf	27.4	28.2	28.2	27.933333	0.46188
	CRA-CRA	25.8	26.4	25.4	25.866667	0.503322
	BP-BP	59.5	58.5	58.8	58.933333	0.51316
	GPF-GPF	28.6	28.6	28.9	28.7	0.173205
	MRA-MRA	35.1	34.7	34.4	34.733333	0.351188
MAX 1-11	IF-IF	51.3	51.1	51.7	51.366667	0.305505
	Pf-Pf	27.2	26.9	26.9	27	0.173205
	CRA-CRA	28.8	29.6	30.2	29.533333	0.702377
	BP-BP	63.1	59.9	59.5	60.833333	1.973153
	GPF-GPF	32	30.9	31.4	31.433333	0.550757
	MRA-MRA	30.6	31.5	31.2	31.1	0.458258

MAX 1-12	IF-IF	53	53.1	53.2	53.1	0.1
	Pf-Pf	26	26.4	26.9	26.433333	0.450925
	CRA-CRA	30.1	31.4	29.9	30.466667	0.814453
	BP-BP	60.4	61.2	61.7	61.1	0.655744
	GPF-GPF	29.2	29.2	28.8	29.066667	0.23094
	MRA-MRA	35.1	33.4	36.1	34.866667	1.36504
MAX 1-13	IF-IF	50.8	50.1	49.7	50.2	0.556776
	Pf-Pf	23.5	23.5	23.5	23.5	0
	CRA-CRA	23.3	24	23.8	23.7	0.360555
	BP-BP	58.5	57.5	57.5	57.833333	0.57735
	GPF-GPF	27	26.8	26.6	26.8	0.2
	MRA-MRA	31.3	30.7	31.4	31.133333	0.378594
MAX 1-14	IF-IF	52.2	52.3	52.7	52.4	0.264575
	Pf-Pf	21.1	20.4	21.2	20.9	0.43589
	CRA-CRA	27	27.3	27.4	27.233333	0.208167
	BP-BP	60.8	62.4	60	61.066667	1.22202
	GPF-GPF	32.9	32.4	32.2	32.5	0.360555
	MRA-MRA	42.2	40.9	41.6	41.566667	0.650641
MAX 1-15	IF-IF	46.7	46.2	45.6	46.166667	0.550757
	Pf-Pf	23.3	22.9	23.5	23.233333	0.305505
	CRA-CRA	27	27.2	27.4	27.2	0.2
	BP-BP	61.6	62.3	62	61.966667	0.351188
	GPF-GPF	30	30	29.7	29.9	0.173205
	MRA-MRA	37.8	38.5	38.7	38.333333	0.472582
MAX 1-16	IF-IF	60.1	59.3	58.4	59.266667	0.85049
	Pf-Pf	25.4	25.9	25.8	25.7	0.264575
	CRA-CRA	32	31.5	31.9	31.8	0.264575
	BP-BP	66.3	66.3	65.2	65.933333	0.635085
	GPF-GPF	32.2	31.3	32.1	31.866667	0.493288
	MRA-MRA	37.2	37	37.6	37.266667	0.305505
MAX 1-17	IF-IF	54.2	53.5	54.7	54.133333	0.602771
	Pf-Pf	24	23.1	24.5	23.866667	0.70946
	CRA-CRA	27.8	27.5	27.5	27.6	0.173205
	BP-BP	60	58.9	59.5	59.466667	0.550757
	GPF-GPF	27.1	27.1	26.5	26.9	0.34641

	MRA-MRA	29.5	30.2	30.8	30.166667	0.650641
MAX 1-18	IF-IF	49.8	49.9	49.3	49.666667	0.321455
	Pf-Pf	28.9	29	28.1	28.666667	0.493288
	CRA-CRA	26.8	26.3	26.1	26.4	0.360555
	BP-BP	58.8	58.6	58.6	58.666667	0.11547
	GPF-GPF	32.3	32.5	32.5	32.433333	0.11547
	MRA-MRA	35	34.6	34.9	34.833333	0.208167
MAX 1-19	IF-IF	47.1	47.4	46.5	47	0.458258
	Pf-Pf	23.2	25.3	21.4	23.3	1.951922
	CRA-CRA	23.4	23.2	23.3	23.3	0.1
	BP-BP	55.4	55.3	55.2	55.3	0.1
	GPF-GPF	26.5	24.9	25.3	25.566667	0.832666
	MRA-MRA	28.9	28.4	28.8	28.7	0.264575
MAX 1-20	IF-IF	51.4	50.9	51.8	51.366667	0.450925
	Pf-Pf	26.3	26	25.6	25.966667	0.351188
	CRA-CRA	29	28.5	28.5	28.666667	0.288675
	BP-BP	63.6	63.6	62.4	63.2	0.69282
	GPF-GPF	28.8	29.5	29.1	29.133333	0.351188
	MRA-MRA	36.5	36.6	36.4	36.5	0.1

Appendix D: Class I Results (Four Landmarks, n=49), Raw Data

CL I PATIENTS (1-49)						
		Timepoint 1	Timepoint 2	Timepoint 3	Mean	SD
MAX 1-01	IF-IF	44.3	44.7	43.6	44.2	0.556776
	CRA-CRA	25.3	26.6	26.5	26.133333	0.723418
	GPF-GPF	25.6	26.1	26.4	26.033333	0.404145
	MRA-MRA	26.5	26.9	25.4	26.266667	0.776745
MAX 1-02	IF-IF	44.6	45.9	46.3	45.6	0.888819
	CRA-CRA	27	27.1	27	27.033333	0.057735
	GPF-GPF	28.7	28.4	28.5	28.533333	0.152753
	MRA-MRA	32.6	30.5	31.3	31.466667	1.059874
MAX 1-03	IF-IF	50.7	50.2	51.6	50.833333	0.70946
	CRA-CRA	25	27.2	26.3	26.166667	1.106044
	GPF-GPF	29.3	29.6	30.3	29.733333	0.51316
	MRA-MRA	33	32.8	33	32.933333	0.11547
MAX 1-04	IF-IF	47.8	47.8	46.8	47.466667	0.57735
	CRA-CRA	22.9	23.5	23.5	23.3	0.34641
	GPF-GPF	26.5	26.6	26.2	26.433333	0.208167
	MRA-MRA	28.5	28.3	28.4	28.4	0.1
MAX 1-05	IF-IF	54.5	54.1	52.8	53.8	0.888819
	CRA-CRA	34.9	34.2	34.2	34.433333	0.404145
	GPF-GPF	32	31	31.2	31.4	0.52915
	MRA-MRA	42	41.7	41.9	41.866667	0.152753
MAX 1-06	IF-IF	59.5	59.6	60	59.7	0.264575
	CRA-CRA	28.5	27.9	29	28.466667	0.550757
	GPF-GPF	30.8	31	31.2	31	0.2
	MRA-MRA	34.2	36.1	37	35.766667	1.429452
MAX 1-07	IF-IF	45.4	45.2	44.5	45.033333	0.472582
	CRA-CRA	25.2	26	25	25.4	0.52915
	GPF-GPF	26.6	26.2	26.2	26.333333	0.23094
	MRA-MRA	32.2	32.8	31.8	32.266667	0.503322
MAX 1-08	IF-IF	52.2	52.5	52.2	52.3	0.173205

	CRA-CRA	27.4	27.8	27.6	27.6	0.2
	GPF-GPF	31	30.9	30.9	30.933333	0.057735
	MRA-MRA	32.5	32.3	33.8	32.866667	0.814453
MAX 1-09	IF-IF	48.2	47.8	48.8	48.266667	0.503322
	CRA-CRA	30.2	28.3	28.9	29.133333	0.971253
	GPF-GPF	28.9	28.7	29.3	28.966667	0.305505
	MRA-MRA	31.3	31.9	32.5	31.9	0.6
MAX 1-10	IF-IF	48.8	48.6	48.4	48.6	0.2
	CRA-CRA	25.8	26.4	25.4	25.866667	0.503322
	GPF-GPF	28.6	28.6	28.9	28.7	0.173205
	MRA-MRA	35.1	34.7	34.4	34.733333	0.351188
MAX 1-11	IF-IF	51.3	51.1	51.7	51.366667	0.305505
	CRA-CRA	28.8	29.6	30.2	29.533333	0.702377
	GPF-GPF	32	30.9	31.4	31.433333	0.550757
	MRA-MRA	30.6	31.5	31.2	31.1	0.458258
MAX 1-12	IF-IF	53	53.1	53.2	53.1	0.1
	CRA-CRA	30.1	31.4	29.9	30.466667	0.814453
	GPF-GPF	29.2	29.2	28.8	29.066667	0.23094
	MRA-MRA	35.1	33.4	36.1	34.866667	1.36504
MAX 1-13	IF-IF	50.8	50.1	49.7	50.2	0.556776
	CRA-CRA	23.3	24	23.8	23.7	0.360555
	GPF-GPF	27	26.8	26.6	26.8	0.2
	MRA-MRA	31.3	30.7	31.4	31.133333	0.378594
MAX 1-14	IF-IF	52.2	52.3	52.7	52.4	0.264575
	CRA-CRA	27	27.3	27.4	27.233333	0.208167
	GPF-GPF	32.9	32.4	32.2	32.5	0.360555
	MRA-MRA	42.2	40.9	41.6	41.566667	0.650641
MAX 1-15	IF-IF	46.7	46.2	45.6	46.166667	0.550757
	CRA-CRA	27	27.2	27.4	27.2	0.2
	GPF-GPF	30	30	29.7	29.9	0.173205
	MRA-MRA	37.8	38.5	38.7	38.333333	0.472582
MAX 1-16	IF-IF	60.1	59.3	58.4	59.266667	0.85049

	CRA-CRA	32	31.5	31.9	31.8	0.264575
	GPF-GPF	32.2	31.3	32.1	31.866667	0.493288
	MRA-MRA	37.2	37	37.6	37.266667	0.305505
MAX 1-17	IF-IF	54.2	53.5	54.7	54.133333	0.602771
	CRA-CRA	27.8	27.5	27.5	27.6	0.173205
	GPF-GPF	27.1	27.1	26.5	26.9	0.34641
	MRA-MRA	29.5	30.2	30.8	30.166667	0.650641
MAX 1-18	IF-IF	49.8	49.9	49.3	49.666667	0.321455
	CRA-CRA	26.8	26.3	26.1	26.4	0.360555
	GPF-GPF	32.3	32.5	32.5	32.433333	0.11547
	MRA-MRA	35	34.6	34.9	34.833333	0.208167
MAX 1-19	IF-IF	47.1	47.4	46.5	47	0.458258
	CRA-CRA	23.4	23.2	23.3	23.3	0.1
	GPF-GPF	26.5	24.9	25.3	25.566667	0.832666
	MRA-MRA	28.9	28.4	28.8	28.7	0.264575
MAX 1-20	IF-IF	51.4	50.9	51.8	51.366667	0.450925
	CRA-CRA	29	28.5	28.5	28.666667	0.288675
	GPF-GPF	28.8	29.5	29.1	29.133333	0.351188
	MRA-MRA	36.5	36.6	36.4	36.5	0.1
MAX 1-21	IF-IF	53.6	53.2	52.4	53.066667	0.61101
	CRA-CRA	26.7	26.4	26.4	26.5	0.173205
	GPF-GPF	27	26.4	26.2	26.533333	0.416333
	MRA-MRA	32.4	33.5	33.5	33.133333	0.635085
MAX 1-22	IF-IF	52.8	53.7	53	53.166667	0.472582
	CRA-CRA	27.2	28.2	27.1	27.5	0.608276
	GPF-GPF	28.8	29	29.1	28.966667	0.152753
	MRA-MRA	30.7	30	30.4	30.366667	0.351188
MAX 1-23	IF-IF	51.7	51.7	52.3	51.9	0.34641
	CRA-CRA	31.9	31.7	30.8	31.466667	0.585947
	GPF-GPF	27.8	28.6	28.2	28.2	0.4
	MRA-MRA	29.2	29.3	30.4	29.633333	0.665833
MAX 1-24	IF-IF	43.1	42.9	42.9	42.966667	0.11547

	CRA-CRA	26.7	28.1	26.8	27.2	0.781025
	GPF-GPF	26	26.2	26	26.066667	0.11547
	MRA-MRA	31.4	30.4	31.2	31	0.52915
MAX 1-25	IF-IF	47	49.4	49.6	48.666667	1.446836
	CRA-CRA	25.2	24.4	24.8	24.8	0.4
	GPF-GPF	26.1	26.3	25.9	26.1	0.2
	MRA-MRA	32.3	32.5	33.6	32.8	0.7
MAX 1-26	IF-IF	57.6	57.4	57	57.333333	0.305505
	CRA-CRA	27.9	28.4	28.6	28.3	0.360555
	GPF-GPF	33.7	33.5	32.9	33.366667	0.416333
	MRA-MRA	35.7	35	35.3	35.333333	0.351188
MAX 1-27	IF-IF	48.1	47.9	48.1	48.033333	0.11547
	CRA-CRA	22.8	23.5	23	23.1	0.360555
	GPF-GPF	28	28	27.5	27.833333	0.288675
	MRA-MRA	32.3	32.1	31.9	32.1	0.2
MAX 1-28	IF-IF	55.2	55	55.4	55.2	0.2
	CRA-CRA	29.3	29.9	29.7	29.633333	0.305505
	GPF-GPF	32.4	32.4	32.4	32.4	0
	MRA-MRA	35.6	35.8	35	35.466667	0.416333
MAX 1-29	IF-IF	52.7	51.8	51.8	52.1	0.519615
	CRA-CRA	25.9	26.1	26.3	26.1	0.2
	GPF-GPF	34.3	34.7	34.5	34.5	0.2
	MRA-MRA	34.4	33.2	34.7	34.1	0.793725
MAX 1-30	IF-IF	55.4	55	55	55.133333	0.23094
	CRA-CRA	25.9	26.6	26.8	26.433333	0.472582
	GPF-GPF	31.9	32.2	32.1	32.066667	0.152753
	MRA-MRA	33.2	34.1	33.3	33.533333	0.493288
MAX 1-31	IF-IF	55.9	55.9	55.5	55.766667	0.23094
	CRA-CRA	30.9	29.7	30.9	30.5	0.69282
	GPF-GPF	34.1	33.5	33.7	33.766667	0.305505
	MRA-MRA	45.7	45.5	45	45.4	0.360555
MAX 1-32	IF-IF	53.1	52.8	53.5	53.133333	0.351188

	CRA-CRA	28.9	29.1	29.2	29.066667	0.152753
	GPF-GPF	27.1	26.5	26.7	26.766667	0.305505
	MRA-MRA	32.2	31.6	32	31.933333	0.305505
MAX 1-33	IF-IF	56.8	56.2	56.3	56.433333	0.321455
	CRA-CRA	30.5	30.9	30.8	30.733333	0.208167
	GPF-GPF	31.2	30.4	30.6	30.733333	0.416333
	MRA-MRA	37	36	36	36.333333	0.57735
MAX 1-34	IF-IF	49	48.2	49.7	48.966667	0.750555
	CRA-CRA	31.7	30.3	29	30.333333	1.350309
	GPF-GPF	28.2	28.8	27.7	28.233333	0.550757
	MRA-MRA	27.3	27.9	29	28.066667	0.862168
MAX 1-35	IF-IF	45.5	45.5	45.9	45.633333	0.23094
	CRA-CRA	20.7	20.7	20.5	20.633333	0.11547
	GPF-GPF	25.2	25	25.2	25.133333	0.11547
	MRA-MRA	30	30	29.8	29.933333	0.11547
MAX 1-36	IF-IF	47.5	47.4	47.3	47.4	0.1
	CRA-CRA	27.6	26.9	27.5	27.333333	0.378594
	GPF-GPF	30.9	30.7	31.4	31	0.360555
	MRA-MRA	33.9	33.8	34.6	34.1	0.43589
MAX 1-37	IF-IF	48.9	48.2	48.7	48.6	0.360555
	CRA-CRA	27.5	27.7	28.1	27.766667	0.305505
	GPF-GPF	27.9	28.5	28.1	28.166667	0.305505
	MRA-MRA	34.4	35.1	34.9	34.8	0.360555
MAX 1-38	IF-IF	42.6	43.1	42.5	42.733333	0.321455
	CRA-CRA	28.8	29	28.2	28.666667	0.416333
	GPF-GPF	23	22.9	22.5	22.8	0.264575
	MRA-MRA	29.5	30.4	30.2	30.033333	0.472582
MAX 1-39	IF-IF	54.6	54.9	54.8	54.766667	0.152753
	CRA-CRA	30.2	29.7	29.8	29.9	0.264575
	GPF-GPF	30.2	30.6	30.2	30.333333	0.23094
	MRA-MRA	37.4	37.6	37.3	37.433333	0.152753
MAX 1-40	IF-IF	53.6	53.7	53.9	53.733333	0.152753

	CRA-CRA	30.6	30.6	30.8	30.666667	0.11547
	GPF-GPF	31.7	32.2	32.1	32	0.264575
	MRA-MRA	31.2	32.3	31.4	31.633333	0.585947
MAX 1-41	IF-IF	48.5	48.1	48.9	48.5	0.4
	CRA-CRA	27.3	27.5	27.5	27.433333	0.11547
	GPF-GPF	30.7	30.1	30.7	30.5	0.34641
	MRA-MRA	31.3	31.7	31.7	31.566667	0.23094
MAX 1-42	IF-IF	53.4	53.8	53.2	53.466667	0.305505
	CRA-CRA	28.7	28.7	28.4	28.6	0.173205
	GPF-GPF	31.3	31.3	30.5	31.033333	0.46188
	MRA-MRA	35	36.2	36	35.733333	0.64291
MAX 1-43	IF-IF	51.4	50	51.1	50.833333	0.737111
	CRA-CRA	32.6	32.6	33.5	32.9	0.519615
	GPF-GPF	33.5	34.2	34.2	33.966667	0.404145
	MRA-MRA	36.4	37	37.2	36.866667	0.416333
MAX 1-44	IF-IF	47	46.7	47.6	47.1	0.458258
	CRA-CRA	25.4	23.8	23.6	24.266667	0.986577
	GPF-GPF	29	29	29.1	29.033333	0.057735
	MRA-MRA	26.2	25.6	26	25.933333	0.305505
MAX 1-45	IF-IF	42.1	41.5	41.6	41.733333	0.321455
	CRA-CRA	26.1	26.3	26.4	26.266667	0.152753
	GPF-GPF	23.5	23.4	23	23.3	0.264575
	MRA-MRA	25.3	25.8	25.1	25.4	0.360555
MAX 1-46	IF-IF	46.3	47.4	47.8	47.166667	0.776745
	CRA-CRA	25.6	26	27	26.2	0.72111
	GPF-GPF	26.2	26.4	26.2	26.266667	0.11547
	MRA-MRA	38.4	37.8	37.1	37.766667	0.650641
MAX 1-47	IF-IF	49.9	50.7	51.9	50.833333	1.006645
	CRA-CRA	30.2	30.1	29	29.766667	0.665833
	GPF-GPF	32.4	32	32.8	32.4	0.4
	MRA-MRA	37	36.4	36.9	36.766667	0.321455
MAX 1-48	IF-IF	48.6	48.8	48.4	48.6	0.2

	CRA-CRA	24.7	24.2	25	24.633333	0.404145
	GPF-GPF	27.9	27.9	28.6	28.133333	0.404145
	MRA-MRA	32.6	32.2	32.8	32.533333	0.305505
MAX 1-49	IF-IF	50.3	50.3	51.1	50.566667	0.46188
	CRA-CRA	28.2	28.6	28.6	28.466667	0.23094
	GPF-GPF	28.9	28.9	29.1	28.966667	0.11547
	MRA-MRA	31.4	31.2	32.4	31.666667	0.64291

Appendix E: Class III Results (Four Landmarks, n=30), Raw Data

CL III PATIENTS (1-30)						
		Timepoint 1	Timepoint 2	Timepoint 3	Mean	SD
MAX 2-01	IF-IF	50.5	50.1	50.9	50.5	0.4
	CRA-CRA	20.5	20.9	21.4	20.933333	0.450924975
	GPF-GPF	27.5	26.7	27.7	27.3	0.529150262
	MRA-MRA	30	30.5	30.5	30.333333	0.288675135
MAX 2-02	IF-IF	54.1	54.4	54.6	54.366667	0.251661148
	CRA-CRA	26.9	25.9	26.3	26.366667	0.503322296
	GPF-GPF	26.9	27.1	27.2	27.066667	0.152752523
	MRA-MRA	30.3	29.5	30	29.933333	0.404145188
MAX 2-03	IF-IF	47.9	48.6	47.9	48.133333	0.404145188
	CRA-CRA	23.4	24.1	23.3	23.6	0.435889894
	GPF-GPF	32.7	32.6	32.4	32.566667	0.152752523
	MRA-MRA	34.7	35.2	35.2	35.033333	0.288675135
MAX 2-04	IF-IF	53	52.6	52.7	52.766667	0.2081666
	CRA-CRA	32	30.7	31.4	31.366667	0.65064071
	GPF-GPF	37.2	36.4	36.5	36.7	0.435889894
	MRA-MRA	39.3	39.1	38.8	39.066667	0.251661148
MAX 2-05	IF-IF	53.4	55.3	54.3	54.333333	0.950438495
	CRA-CRA	23.5	24.6	23.4	23.833333	0.665832812
	GPF-GPF	32.2	32.2	32.2	32.2	0
	MRA-MRA	35.3	33.9	34.5	34.566667	0.702376917
MAX 2-06	IF-IF	47.6	47.5	47.7	47.6	0.1
	CRA-CRA	31.5	31.1	31.8	31.466667	0.351188458
	GPF-GPF	30.6	30.2	30.5	30.433333	0.2081666
	MRA-MRA	34.3	33.9	33.8	34	0.264575131
MAX 2-07	IF-IF	55.7	56.4	56.9	56.333333	0.602771377
	CRA-CRA	30.1	30.5	30.2	30.266667	0.2081666
	GPF-GPF	37.1	37.5	37.5	37.366667	0.230940108
	MRA-MRA	38.8	38.5	38.7	38.666667	0.152752523
MAX 2-08	IF-IF	52.4	52.3	51.2	51.966667	0.665832812

	CRA-CRA	26.5	26.3	26.2	26.333333	0.152752523
	GPF-GPF	29.6	29.5	29.4	29.5	0.1
	MRA-MRA	35.3	35.7	35.5	35.5	0.2
MAX 2-09	IF-IF	49.3	48.9	49.9	49.366667	0.503322296
	CRA-CRA	29	28.6	29.1	28.9	0.264575131
	GPF-GPF	28.7	29.1	28.8	28.866667	0.2081666
	MRA-MRA	34.7	34.1	34.1	34.3	0.346410162
MAX 2-10	IF-IF	43.4	44	43.6	43.666667	0.305505046
	CRA-CRA	25.7	25.3	25	25.333333	0.351188458
	GPF-GPF	29.6	29.4	29.1	29.366667	0.251661148
	MRA-MRA	29.3	29.5	29.2	29.333333	0.152752523
MAX 2-11	IF-IF	45.5	46.1	45.7	45.766667	0.305505046
	CRA-CRA	23	22.8	22.5	22.766667	0.251661148
	GPF-GPF	28.8	28.9	29.1	28.933333	0.152752523
	MRA-MRA	29.8	30	28.6	29.466667	0.757187779
MAX 2-12	IF-IF	54	54.9	54.2	54.366667	0.472581563
	CRA-CRA	32.4	31.6	32	32	0.4
	GPF-GPF	31.3	31.1	31.4	31.266667	0.152752523
	MRA-MRA	34.6	34.6	35	34.733333	0.230940108
MAX 2-13	IF-IF	46.2	45.3	45.9	45.8	0.458257569
	CRA-CRA	20.2	20.3	19.8	20.1	0.264575131
	GPF-GPF	27.2	26	26.9	26.7	0.6244998
	MRA-MRA	29.9	29.3	29.6	29.6	0.3
MAX 2-14	IF-IF	49.6	49.6	50.4	49.866667	0.461880215
	CRA-CRA	25.9	25.8	26.1	25.933333	0.152752523
	GPF-GPF	30.2	30.2	30.2	30.2	0
	MRA-MRA	31.9	31.9	31.5	31.766667	0.230940108
MAX 2-15	IF-IF	42	42.3	42.8	42.366667	0.404145188
	CRA-CRA	25.8	26.9	26.1	26.266667	0.56862407
	GPF-GPF	28.4	28.3	28.3	28.333333	0.057735027
	MRA-MRA	34.6	34	34.2	34.266667	0.305505046
MAX 2-16	IF-IF	50.9	51.1	50.9	50.966667	0.115470054

	CRA-CRA	27.3	27.3	27	27.2	0.173205081
	GPF-GPF	30.9	31.1	30.5	30.833333	0.305505046
	MRA-MRA	35.1	34.8	34.8	34.9	0.173205081
MAX 2-17	IF-IF	46.1	45.5	45.8	45.8	0.3
	CRA-CRA	22.6	22.2	21.2	22	0.721110255
	GPF-GPF	34.3	34.4	34.2	34.3	0.1
	MRA-MRA	34.6	34.8	35.2	34.866667	0.305505046
MAX 2-18	IF-IF	45.9	45.4	45.7	45.666667	0.251661148
	CRA-CRA	24.6	24.8	25.1	24.833333	0.251661148
	GPF-GPF	31.1	30.6	30.4	30.7	0.360555128
	MRA-MRA	31.4	32	31.7	31.7	0.3
MAX 2-19	IF-IF	45.2	46.1	46	45.766667	0.493288286
	CRA-CRA	25.2	24.7	25.4	25.1	0.360555128
	GPF-GPF	30.6	29.9	31	30.5	0.556776436
	MRA-MRA	28.9	28.9	28.6	28.8	0.173205081
MAX 2-20	IF-IF	47.7	47.8	48.1	47.866667	0.2081666
	CRA-CRA	25.6	25.3	25.3	25.4	0.173205081
	GPF-GPF	29.1	29.1	29.1	29.1	0
	MRA-MRA	32.1	32.3	32.1	32.166667	0.115470054
MAX 2-21	IF-IF	55.1	55.4	54.9	55.133333	0.251661148
	CRA-CRA	27.9	27.5	27.9	27.766667	0.230940108
	GPF-GPF	31.8	32.3	31.8	31.966667	0.288675135
	MRA-MRA	40.8	41.3	40.6	40.9	0.360555128
MAX 2-22	IF-IF	54	54	54.6	54.2	0.346410162
	CRA-CRA	29.2	29.4	29.7	29.433333	0.251661148
	GPF-GPF	29.9	29.7	29.3	29.633333	0.305505046
	MRA-MRA	36.7	37.1	37	36.933333	0.2081666
MAX 2-23	IF-IF	48.8	49.3	49.6	49.233333	0.404145188
	CRA-CRA	27.7	28.2	28.7	28.2	0.5
	GPF-GPF	28.5	28.3	28.2	28.333333	0.152752523
	MRA-MRA	33.9	33.5	34	33.8	0.264575131
MAX 2-24	IF-IF	55.6	55.2	55.7	55.5	0.264575131

	CRA-CRA	30.4	29.5	30	29.966667	0.450924975
	GPF-GPF	32	33	32.4	32.466667	0.503322296
	MRA-MRA	35.7	35.5	35.6	35.6	0.1
MAX 2-25	IF-IF	52.3	51.8	52.8	52.3	0.5
	CRA-CRA	26.6	26.3	27	26.633333	0.351188458
	GPF-GPF	30.1	30.8	30.2	30.366667	0.37859389
	MRA-MRA	34.1	32.9	33.4	33.466667	0.602771377
MAX 2-26	IF-IF	44	44.2	44.7	44.3	0.360555128
	CRA-CRA	20.9	20.7	20.9	20.833333	0.115470054
	GPF-GPF	27	27.5	27.5	27.333333	0.288675135
	MRA-MRA	29.6	27.9	28.1	28.533333	0.929157324
MAX 2-27	IF-IF	46.3	46.6	46.2	46.366667	0.2081666
	CRA-CRA	25.1	24.8	24.7	24.866667	0.2081666
	GPF-GPF	32.8	31.7	31.5	32	0.7
	MRA-MRA	33.5	33.6	33.7	33.6	0.1
MAX 2-28	IF-IF	50.1	50.4	50.4	50.3	0.173205081
	CRA-CRA	24.2	24.7	24	24.3	0.360555128
	GPF-GPF	36.6	36.5	37	36.7	0.264575131
	MRA-MRA	32.7	33	33.9	33.2	0.6244998
MAX 2-29	IF-IF	56.6	56	56.7	56.433333	0.37859389
	CRA-CRA	30	28.7	29.3	29.333333	0.65064071
	GPF-GPF	35.3	35.5	35.5	35.433333	0.115470054
	MRA-MRA	42.2	41.9	42.2	42.1	0.173205081
MAX 2-30	IF-IF	53.3	53.7	53.7	53.566667	0.230940108
	CRA-CRA	20.1	19.6	20.1	19.933333	0.288675135
	GPF-GPF	34.6	33.6	34.2	34.133333	0.503322296
	MRA-MRA	28.9	27.7	27.9	28.166667	0.642910051

LITERATURE CITED

1. Banning LM, Garard N, Steinberg BJ, Bogdanoff E. Treatment of transverse maxillary deficiency with emphasis on surgically assisted-rapid maxillary expansion. Compendium 1996;17:170-178.

2. Basaran G, Hamamci N, Hamamci O. Comparison of Dental Arch Widths in Different Types of Malocclusions. World J Orthod 2008;9:62.e20-28.

3. Betts NJ, Vanarsdall RL, Barber HD. Diagnosis and treatment of transverse maxillary deficiency. Int J Adult Orthod Orthognath Surg 1995;10:75-96.

4. Bjork A, Skieller V. Growth of the maxilla in three dimensions as revealed radiographically by the implant method. Br J Orthod 1977;4:53-64.

5. Braun S, Hnat W, Fender DE, Legan HL. The form of the Human Dental Arch. Angle Orthod 1998;68(1):29-36.

6. Caspersen L, Christensen I, Kjaer I. Inclination of the infraorbital canal studies on dry skulls expresses the maxillary growth pattern: a new contribution to the understanding of change in inclination of ectopic canines during puberty. Acta Odontologica Scandinavida 2009;67:341-45.

7. Cevidanes LHS, Styner MA, Proffit WR. Image analysis and superimposition of 3-dimesional cone-beam computed tomography models. Am J Orthod Dentofacial Orthop 2006;129:611-8.

8. Chen F, Terada K, Wu L, Saito I. Longitudinal Evaluation of the Intermaxillary Relationship in Class III Malocclusions. Angle Orthod 2006:76:955.

9. Chen F, Terada K, Yang L, Saito I. Dental Arch Widths and Mandibular-Maxillary Base Widths in Class III Malocclusions from ages 10 to 14. Am J Orthod Dentofacial Orthop 2008;133:65-9.

10. Cho HJ. A three-dimensional cephalometric analysis. J Clinical Orthod 2009;43:235-52.

11. Cortella S, Schofer FS, Ghafari J. Transverse Development of the Jaws: Norms for the Posteroanterior Cephalometric Analysis. Am J Orthod Dentofac Orthop 1997;112:519-22.

12. Franchi L, Baccetti T. Transverse maxillary deficiency in Class II and Class III malocclusions: a cephalometric and morphometric study on postero-anterior films. Orthod Craniofacial Res 2005;8:21-28.

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

14. Garrett BJ, Caruso JM, Rungcharassaeng K, Farrage JR, Kim JS, Taylor GD. Skeletal Effects to the Maxilla after Rapid Maxillary Expansion assessed With Cone-Beam Computed Tomography. Am J Orthod Dentofacial Orthop 2008;134:8-9.

15. Goldenberg DC, Alonso N, Goldenberg FC, Gebrin ES, Amaral TS, Scanavini MA, Ferrerira MC. Using Computed Tomography to evaluate maxillary changes after surgically assisted rapid palatal expansion. J Craniofacial Surg 2007;18:302-311.

16. Gottlieb EL, Nelson AH, Vogels DS. JCO study of orthodontic diagnosis and treatment procedures: part 1, results and trends. J Clin Orthod 1990;25:145-56.

17. Grummons D, Kappeyne van de Coppelo MA. A frontal asymmetry analysis. J Clin Orthod 1987;21:448-465.

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

19. Hesby RM, Marshall SD, Dawson DV, Southard KA, Casko JS, Franciscus RB, Southard TE. Transverse Skeletal and Dentoalveolar Changes during Growth. Am J Orthod Dentofacial Orthop 2006;130:721-31.

20. Holberg C, Steinhauser S, Geis P, Rudzki-Janson I. Cone-Beam Computed Tomography in Orthodontics: Benefits and Limitations. J Orofac Orthop 2005;66:434-44.

21. Huertas D, Ghafari J. New Posteroanterior Cephalometric Norms: A comparison with Craniofacial Measures of Children Treated with Palatal Expansion. Angle Orthod 2001;71:285-292.

22. Jacobs JC, Bell WH, Williams CE. Control of the transverse dimension with surgery and orthodontics. Am J Orthod 1980;77:284-306 (NEED)

23. Lagravere MO, Gordon J, Guedes Ines, Flores-Mir C. Reliability of traditional cephalometric landmarks as seen in three-dimensional analysis in maxillary expansion treatments. Angle Orthod 2009;79:1047-56.

24. Loddi PP, Pereira MD, Wolosker AB, Hino CT, Kreniski TM, Ferreira LM. Transverse effects after surgically assisted rapid maxillary expansion in the midpalatal suture using computed tomography. J Craniofac Surg. 2008;19:433-438.

25. Lux D, Conradt C, Burden D, Komposh G. Transverse development of the craniofacial skeleton and dentition between 7 and 15 years of age-a longitudinal postero-anterior cephalometric study. Eur J Orthod 2004;26:31-42.

26. Menon S, Manerikar R, Sinha R. Surgical Management of Transverse Maxillary Deficiency in Adults. J Maxillofac Oral Surg 2010;9(3):241-246.

27. Podesser B, Williams S, Batleon H, Imhof H. Quantification of transverse maxillary dimensions using computed tomography: a methodological and reproducibility study. Eur J Orthod 2004;26:209-215.

28. Proffit WR, Fields Jr HW, Sarver DM. Comtemporary Orthodontics. Stl. Louis: Mosby Elsevier; 2007:p.208.

29. Ricketts, Robert. Perspectives in the clinical application of cephalometrics, the first fifty years. Angle Orthod 1981;51:115-50.

30. Sejrsen B, Kjaer I, Jakobsen J. Human palatal growth evaluated on medieval crania using nerve canal openings as references. Am J Phys Anthropol. 1996 Apr;99(4):603-11.

31. Slaj M, Spalj S, Pavlin D, Illes D, Slaj M. Dental Archforms in dentoalveolar Class I, II and III. Angle Orthod 2010;80:919-924.

32. Sujatha N, Manjunath KY, Balasubramanyam V. Variations of the location of the greater palatine foramina in dry human skulls. Indian J Dent Res. 2005 Jul-Sep;16(3):99-102.

33. Swennen G, Schutyser F, Barth E, De Groeve P. A new method of 3-D cephalometry part I: the anatomic cartesian 3-d reference system. J Cranifac Surg 2006;17:314-325.

34. Timms DJ. A study of basal movement with rapid maxillary expansion. Am J Orthod 1980;4:123-127.

35. Uysal T, Usumez S, Memill B, Sari Z. Dental and Alveolar Arch Widths in Normal Occlusion and Class III Malocclusion. Angle Orthod 2005; 75:809-813.

36. Vanarsdall, Transverse dimension and long-term stability, Semin Orthod 1999;**5:**171–180.