9-2013

Correlating Vomer with Ceph Vectors in High and Low Mandibular Plane Angle Cases

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Correlating Vomer with Ceph Vectors in High and Low Mandibular Plane Angle Cases

by

Christopher James Wood

A Thesis submitted in partial satisfaction of
the requirements for the degree
Master of Science in Orthodontics and Dentofacial Orthopedics

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September 2013

Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to the members of my committee for their guidance and direction in completing this project. I would also like to thank my family for their support through this endeavor.

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ABBREVIATIONS

CBCT	Cone Beam Computed Tomography
DICOM	Digital Imaging and Communications in Medicine
AIVA	Anterior Inferior Vomer Axis
PIVA	Posterior Inferior Vomer Axis
FA	Facial Axis
YA	Y-axis
Na	Nasion
Ba	Basion
CVFG	Calculated Vector of Facial Growth

ABSTRACT OF THE THESIS

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Plane Angle Cases

by

Christopher James Wood

Master of Science
Graduate Program in Orthodontics and Dentofacial Orthopedics
Loma Linda University, September 2013
Dr. R. David Rynearson, Chairperson

Introduction: Growth of the maxilla and mandible follow identifiable vectors of facial growth such as the Rickett's Facial Axis (FA) and the Down's Y-axis (YA). The purpose of this study was to evaluate the correlation between the anterior inferior vomer axis (AIVA) and posterior inferior vomer axis (PIVA) with the FA and YA in cases with high (32 degrees and above) and low (20 degrees and below) mandibular plane angles.

Methods: Pretreatment cone beam computed tomography (CBCT) scans of 94 patients treated at the Loma Linda University Graduate Orthodontic Clinic meeting the inclusion criteria were used in this retrospective study. The inclusion criteria were: bilateral Class I occlusion, no craniofacial malformations, no known airway problems, a pretreatment CBCT, Ricketts mandibular plane angle 20 degrees and below or 32 degrees and above, age 11-15 or 19-45. Patients were separated into high angle and low angle groups determined by Ricketts mandibular plane angle. Subjects in both high and low angle groups were separated into two age groups (11-15 and 19-45). The FA and YA were compared with the PIVA and the AIVA for each group. The nasion-basion plane was used as a reference plane.

Results: The AIVA and PIVA were significantly correlated with the FA (P =0.001, P =0.016) and YA (P ≤0.0001, P ≤0.0001) in low angle subjects. In high angle subjects, the PIVA was significantly correlated with FA (P ≤0.0001) and YA (P ≤0.0001). The AIVA in high angle subjects was not correlated with either FA (P =0.415) or YA (P =0.399).

Conclusions: The PIVA likely represents a combination vector of both drift and displacement of the maxilla. The AIVA likely represents a vector of principally maxillary displacement.

CHAPTER ONE

LITERATURE REVIEW

The vomer bone is a mid-sagittal structure that articulates with the nasal septal cartilage anteriorly, the palatine bone and maxilla inferiorly, the perpendicular plate of the ethmoid bone superiorly and body of the sphenoid bone superior-posteriorly (Fig 1).

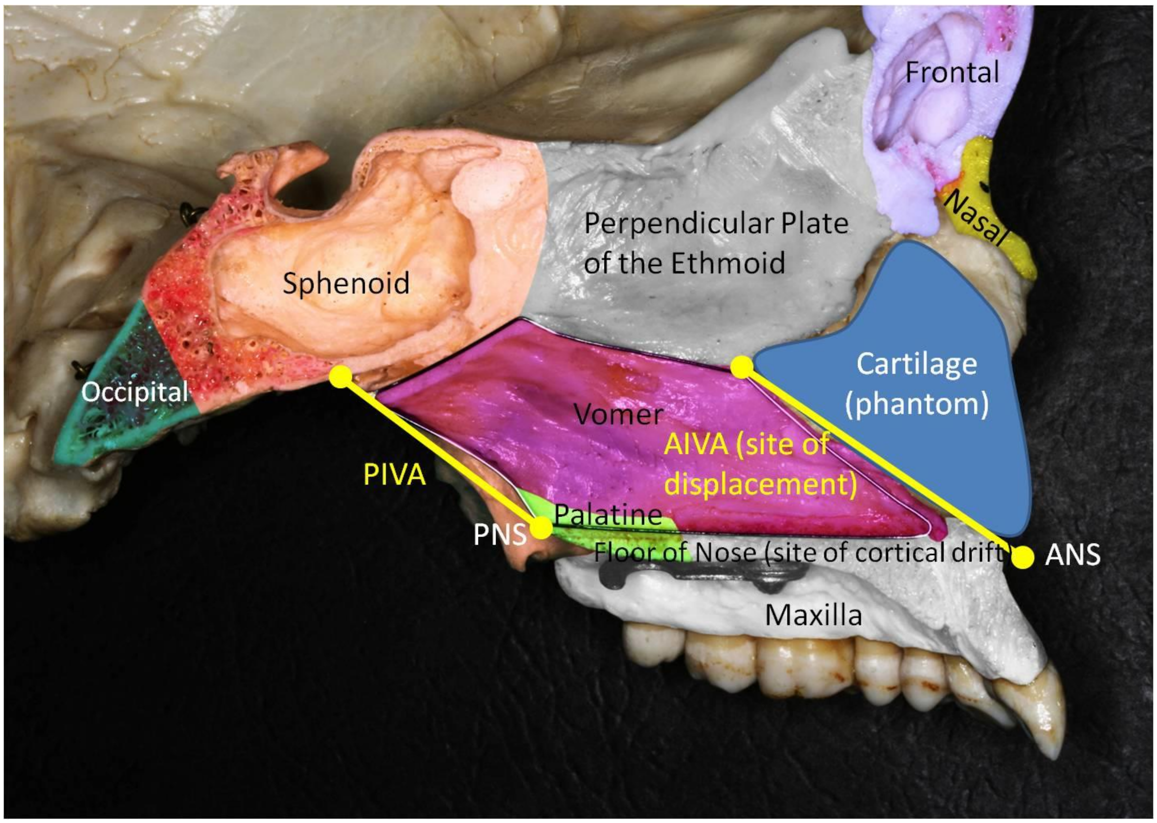

Fig 1. A wire is shown outlining the vomer bone on a dried skull with labeled structures (mid-sagittal view). The cartilage (phantom) represents where the cartilaginous nasal septum would be in a live patient. The anterior nasal spine is labeled as ANS and the posterior nasal spine is labeled as PNS. The yellow lines indicate the posterior inferior vomer axis (PIVA) and anterior inferior vomer axis (AIVA).

When considering the growth of the midface one would expect that attention would be focused on the vomer bone considering its central location among other facial bones.

The vomer bone appears to be ideally placed to either affect or contribute to the downward and forward growth of the maxilla and face in general. Numerous studies have been conducted to observe the growth of the face.[1,2,3] It should also be noted that many early concepts have been refuted as new information was collected and analyzed. The complexities of the growth of the human face remain to be fully understood and necessitate further investigation of the structures comprising the face. Despite the fact that great energy has been expended to understand facial growth, the literature is scarce when it comes to studying the vomer bone itself and how it may contribute to the growth of the midface. This review summarizes some of the historical and contemporary ideas of craniofacial growth and outlines some of the research that has been conducted regarding the vomer bone and some of its adjacent structures.

Growth of the middle face is observed to expand in width, depth and height.[2] According to Scott, growth of the middle face can be separated into two phases. The first, which includes birth to approximately age seven, is characterized by the proliferation of the nasal septal cartilage displacing the maxilla down and forward. The second phase occurs after the fusion of the perpendicular plate of the ethmoid bone to the vomer bone around age seven. Cortical drift becomes the key factor in the downward and forward growth in this second phase.[2] A recent study on the growth rate of the nasal septal cartilage conducted on Hanford minipigs found that the growth rate of the cartilage was significantly higher than at the nasofrontal suture. The authors concluded that their findings were consistent with the belief that growth of the nasal septal cartilage might drive growth of the nasofrontal suture.[4]

Research by Melsen on autopsy specimens, however, found that the increase in dimension of the nasal septum postnatally is primarily due to apposition at the posterior margin and on the superior surface of the vomer bone. The posterior margin in Melsen's study corresponds to the region of the Posterior Inferior Vomer Axis (PIVA) that is used in this study (Fig 1). Melsen defined the superior surface to be the junction between the vomer and sphenoid bones. Apposition at these sites during growth of the craniofacial complex results in a downward and forward displacement of the vomer in relation to the cartilaginous nasal septum and perpendicular plate of the ethmoid bone. This displacement results in a sliding of the vomer bone in relation to the anterosuperior portion of the nasal septum. Melsen concludes that Scott's suggestion that the nasal septal cartilage can propel the maxillary complex forward is unlikely.[5]

According to research by Thilander, in fetal life the midface in the midsagittal plane consists entirely of cartilage.[6] This cartilagenous plate represents the nasal septum and portions of it become ossified to form the vomer and ethmoid bones. The growth of the nasal septum is considered to play an influential role in the development of the midface prenatally and in the early stages of postnatal growth.

Profitt states that the downward and forward growth of maxilla is accomplished by passive displacement, being propelled forward by growth of the cranial base, as well as by growth at the sutures. Passive displacement is an important mechanism for maxillary growth until about age seven, when neural growth is complete. After age seven, growth at the sutures becomes the predominant mechanism of maxillary growth, although passive displacement does continue to be a minor contributor. As the maxilla is displaced down and forward, the bones it articulates with also grow in size.[7]

Ranly states that lateral growth of the bones of the middle face is primarily accomplished by cortical drift and displacement.[8] Immediately after birth, growth of the sagittal suture system allows for the expansion in width of the skull. The growing brain, in conjunction with cartilage growth, contributes to the increase in width of the skull. The vertical growth of the face is quite substantial, in comparison to horizontal growth, and doubles during growth with the majority of the observed growth being due to expansion of the nasal cavity.[8] Bjork was able to quantify the amount of observed maxillary growth through his implant study and determined that displacement was responsible for 43% of maxillary lowering and the remaining 57% was due to alveolar apposition.[1]

According to Moss and his functional matrix theory, tissues and spaces associated with certain bodily functions respond to the functions of their respective functional matrix. He describes the palatine process of the maxilla as being responsive to respiratory function on the superior surface where it articulates with the vomer and septal cartilages and also to digestive and vocal functions on its inferior surface. Moss states that the characteristics of bones, (including their sizes, shapes, positions and growth) are all results of their responses to the growth of their functional matrix.[3] Therefore, according to Moss, vomer growth would be a result of increasing nasal airway growth.

Kimes research with fetal specimens of cleft lip and palate and normal fetal specimens ruled out nasal airway growth as being an early causal growth mechanism.[9] This conclusion was drawn from the observation of nasal septal cartilage and the vomer bone hyperplasia in cleft lip and palate specimens which also exhibited reduced nasal volume compared to controls. The speculation offered by these authors was that there may be a causal relationship between the hyperplastic nasal septal cartilage and the hyperplastic vomer.[9]

Latham et. al. found that growing dogs, which had surgically placed clefts and a major portion of the vomer bone removed, experienced reduced growth in the antero-posterior dimension. However, the dogs with congenital complete clefts of the hard palate experience normal growth. He concluded that the difference in growth between groups of dogs may be explained in terms of the role of the vomer bone in growth and support of the upper jaw.[10]

Friede used metallic implants and roentgencephalometry on infants with craniofacial anomalies and observed growth between the vomer and premaxilla as well as between the vomer and sphenoid bone. Friede believed that the sliding movement between the above mentioned bones is likely to occur in order to allow the distinct forward growth of the midface relative to the cranial base.[11]

A Master's Thesis by Pulfer examined the anterior and posterior slopes of the vomer bone and related those slopes to the cephalometric measurement of the Facial Axis (FA) of the Ricketts analysis as well as to the Y-axis (YA) from the Downs analysis. He suggested that the anterior inferior vomer axis (AIVA) is likely to represent a vector of maxillary displacement and the PIVA represents a vector of both displacement and cortical drift.[12] Pulfer's research analyzed CBCT images of mesofacial patients.

Facial type is an important consideration when treating a patient. A low angle face may tolerate treatment modalities that in a high angle face would cause occlusal disharmony. Understanding a patient's particular facial type gives insight into the type and or direction of growth the patient may follow during and after treatment. A patient's growth during and after treatment greatly effects the prognosis of a case.[13] Therefore, a thorough understanding of patient growth patterns is critical to making an accurate diagnosis and subsequent orthodontic treatment plan.

Until the introduction of cone beam imaging it was impossible to accurately identify landmarks associated with the vomer bone and to construct the associated anterior and posterior slopes of the vomer on live patients.

Landmark identification errors on cone beam derived cephalograms have been found to be comparable to those of conventional digital cephalograms[14]. Using the 3D MPR view has been found to be more accurate than conventional lateral cephalograms.[15] It is through this technique that anatomical structures such as the vomer bone can be identified, which could not be done on a conventional lateral cephalogram. The plotted landmarks on the CBCT slices can then be used to construct planes from the CBCT derrived lateral ceph and a comparison of the slopes of the vomer bone can be made to facial type or any other desired measurement of a cephalometric tracing.

Researchers over the years have tried to accurately understand and describe craniofacial growth. As new technologies and techniques become available the understanding of how the face grows improves. At this point there is still disagreement on the exact mechanisms of how each area and bone of the face grows. Therefore more research needs to be conducted. It is evident that there is a combination of drift and displacement occurring throughout growth and development.

CHAPTER TWO

CORRELATING VOMER WITH CEPH VECTORS IN HIGH AND LOW MANDIBULAR PLANE ANGLE CASES

Abstract

Introduction: Growth of the maxilla and mandible follow identifiable vectors of facial growth such as the Rickett's Facial Axis (FA) and the Down's Y-axis (YA). The purpose of this study was to evaluate the correlation between the anterior inferior vomer axis (AIVA) and posterior inferior vomer axis (PIVA) with the FA and YA in cases with high (32 degrees and above) and low (20 degrees and below) mandibular plane angles.

Methods: Pretreatment cone beam computed tomography (CBCT) scans of 94 patients treated at the Loma Linda University Graduate Orthodontic Clinic meeting the inclusion criteria were used in this retrospective study. The inclusion criteria were: bilateral Class I occlusion, no craniofacial malformations, no known airway problems, a pretreatment CBCT, Ricketts mandibular plane angle 20 degrees and below or 32 degrees and above, age 11-15 or 19-45. Patients were separated into high angle and low angle groups determined by Ricketts mandibular plane angle. Subjects in both high and low angle groups were separated into two age groups (11-15 and 19-45). The FA and YA were compared with the PIVA and the AIVA for each group. The nasion-basion plane was used as a reference plane.

Results: The AIVA and PIVA were significantly correlated with the FA (P =0.001, P =0.016) and YA (P ≤0.0001, P ≤0.0001) in low angle subjects. In high angle subjects, the PIVA was significantly correlated with FA (P ≤0.0001) and YA (P ≤0.0001). The AIVA in high angle subjects was not correlated with either FA (P =0.415) or YA (P =0.399).

Conclusions: The PIVA likely represents a combination vector of both drift and displacement of the maxilla. The AIVA likely represents a vector of principally maxillary displacement.

Introduction

A thorough understanding of craniofacial growth is fundamental to the proper treatment of orthodontic patients. Growth of the middle face is observed to expand in width, depth and height.[2] According to Scott, growth of the middle face can be separated into two phases. The first, which includes birth to approximately age seven, is characterized by the proliferation of the nasal septal cartilage displacing the maxilla down and forward. The second phase occurs after the fusion of the perpendicular plate of the ethmoid bone to the vomer bone around age seven. Cortical drift becomes the key factor in the down and forward growth in this second phase. [2]

The vertical growth of the face is substantial, in comparison to horizontal growth, and doubles during growth with the majority of the observed growth being due to expansion of the nasal cavity.[8] Bjork was able to quantify the amount of observed maxillary growth through his implant study and determined that displacement was responsible for 43% of maxillary lowering and the remaining 57% was due to alveolar apposition.[1]

The purpose of this study was to evaluate AIVA (anterior inferior vomer axis) and PIVA (posterior inferior vomer axis) with the FA (facial axis) and YA (y-axis) on cases with very high and very low mandibular plane angles.

No prior published study was found that determines if there exists a correlation between the slope of the vomer bone and facial type. Growth of the midface is still not completely understood and more research needs to be conducted regarding relationships between bones of the midface. The limited research on the vomer bone in orthodontics is likely due to the inability to determine the slopes and shape of the vomer bone from two-dimensional radiography. The introduction of CBCT into orthodontics has provided a way to evaluate hard tissues that could not be evaluated previously with traditional orthodontic imaging.

Materials and Methods

Pretreatment cone beam computed tomography (CBCT) scans of 94 patients treated at the Loma Linda University Graduate Orthodontic Clinic meeting the inclusion criteria were used in this retrospective study. The inclusion criteria were: bilateral Class I occlusion, no craniofacial malformations, no known airway problems, a pretreatment CBCT, Ricketts mandibular plane angle 20 degrees and below or 32 degrees and above, age 11-15 or 19-45. Patients were separated into high angle and low angle groups determined by Ricketts mandibular plane angle. Subjects in both high and low angle groups were separated into two age groups (11-15 and 19-45). The 11-15 year olds were considered the growing patients near the adolescent growth spurt. Subjects in the 19-45 year old age group were considered to have reached skeletal maturity. There were 44 high angle cases (mandibular plane angle 32 degrees and above), composed of 14 males (11 adolescent and 3 adult) and 30 females (15 adolescent and 15 adult). There were 50 low angle cases (mandibular plane angle 20 degrees and below), 23 male (15 adolescent and 8 adult), 27 female (15 adolescent and 13 adult).

The slopes of the vomer bone were named and measured according to the method outlined by Pulfer.[12] The PIVA is a straight line connecting the tip of the posterior nasal spine to hormion (the most dorsal contact point of the vomer with the sphenoid) (Fig 1 and 2). The AIVA is a straight line connecting the tip of the anterior nasal spine to the point where the superior margin of the vomer meets the perpendicular plate of the ethmoid (Fig 1 and 3). The above method for measuring the slopes of the vomer was used to maintain consistency with the previous study and because the landmarks used are more easily identifiable. Ricketts nasion-basion plane, the anatomical cranial base, as well as FA and YA were also identified and constructed (Fig 4).

CBCTs were taken using the NewTom 3G or NewTom 5G and landmarks were identified using OsiriX (OsiriX, Geneva, Switzerland, version 3.5.1) software. Landmarks were identified by scrolling through sagittal slices and then marked. Points were propagated throughout the series and a lateral view of the skull with constructed slopes and planes was printed at life size (Fig 4). One investigator made all measurements by hand (C.W.). The AIVA, PIVA, Facial axis, and Y-axis were measured by the inferior angles they formed with the nasion-basion plane (Fig 4).

Mandibular plane angle was determined from a lateral cephalometric image generated from the CBCT volume using Dolphin imaging (Dolphin version 11.5). The image was printed and measurements were made by hand.

Fig 2. Identification of the PIVA on a CBCT slice. Identical images with the PIVA identified by a green line in the image on the right.

Fig 3. Identification of the AIVA on a CBCT slice. Identical images with the AIVA identified by a green line in the image on the right.

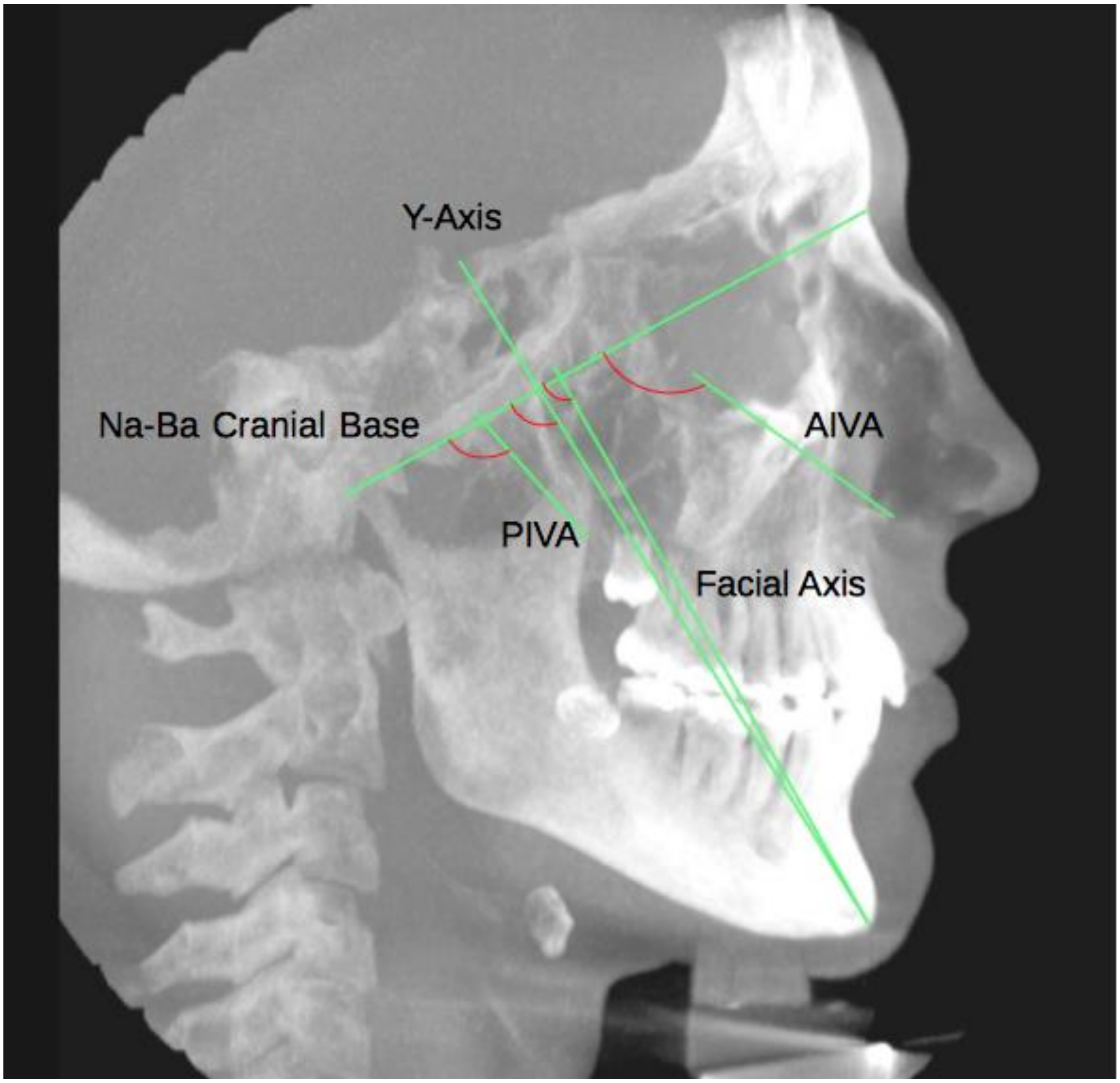

Fig 4. A CBCT image with reference planes labeled including the PIVA, YA (Down's analysis), FA (Ricketts analysis) and AIVA. The Ricketts Na-Ba Cranial Base was the reference plane for measurements. The red arcs indicate measured angles.

Measurement repeatability was tested 1 month after all data had been collected by randomly selecting 10 of the original cases to have points re-identified, planes re-constructed and angles re-measured.

The PIVA, Facial Axis, Y-axis and AIVA were all measured by the inferior angle they form with the nasion-basion plane (Fig 4). In the Down's cephalometric analysis, the Y-axis is measured by the angle it forms with Frankfort horizontal. Therefore, the values for the Y-axis in this study are not comparable to the Y-axis values in the Down's analysis. However, since the same points of sella and ganthion are used in this study and in the Down's analysis, the vector of the Y-axis remains unchanged. The data collected in this study was analyzed using the Pearson Correlation Coefficient, independent sample t-test, Spearmans Correlation Coefficient, One Way ANOVA, and interclass correlation.

Results

The low angle group including both age groups had a mean PIVA of 105.7°, YA 96.0°, FA 93.1°, AIVA 121.4°. In the high angle group including both age groups the mean PIVA was 102.8°, YA 86.7°, FA 82.5°, AIVA 114.5° (Table 1). The AIVA and PIVA were significantly correlated with the FA ($P = 0.001$, $P = 0.016$) and YA ($P \leq 0.0001$, $P \leq 0.0001$) in low angle subjects. In high angle subjects, the PIVA was

Table 1. Summary table of measured values (a composite).

Group		Mean	Std. Deviation
Age	Low (n=50)	19.2	9.395
	High (n=44)	18.8	9.171
PIVA	Low (n=50)	105.7	6.883
	High (n=44)	102.8	6.295
Y-axis	Low (n=50)	96.0	3.4594
	High (n=44)	86.7	4.1631
FA	Low (n=50)	93.1	3.8030
	High (n=44)	82.5	4.5921
AIVA	Low (n=50)	121.4	7.114
	High (n=44)	114.5	7.079

significantly correlated with FA (P ≤0.0001) and YA (P ≤0.0001). The AIVA in high angle subjects was not correlated with either FA (P =0.415) or YA (P =0.399) (Table 2).

Table 2. Correlations by mandibular plane angle (a composite).

Group			Y-axis	FA
Low (n=50)	PIVA	Pearson Correlation	0.48	0.34
		Sig. (2-tailed)	.000*	.016*
	AIVA	Pearson Correlation	0.48	0.46
		Sig. (2-tailed)	.000*	.001*
High (n=44)	PIVA	Pearson Correlation	0.57	0.51
		Sig. (2-tailed)	.000*	.000*
	AIVA	Pearson Correlation	.130	.126
		Sig. (2-tailed)	.399	.415

*Significance at 0.05 level

In the low angle group the AIVA was correlated with YA and FA in both male (P =0.022, P =0.029) and female groups (P =0.007, P =0.009), but correlations were stronger in the female group. In the low angle group the PIVA was correlated with YA and FA for the female group (P =0.001, P =0.027), but not for the male group (P =0.091, P =0.242) (Table 3).

In the high angle group the AIVA was not correlated with YA or FA in either the male (P =0.579, P =0.592) or female groups (P =0.582, P =0.590). The PIVA for the high angle group showed correlations with both YA and FA in both male (P =0.008, P =0.012) and female (P =0.002, P =0.019) groups (Table 3).

Table 3. Correlations of YA and FA with mandibular plane angle and gender.					
	Group			Y-axis	FA
Low	Female (n=27)	PIVA	Pearson Correlation	0.59	0.43
			Sig. (2-tailed)	.001*	.027*
		AIVA	Pearson Correlation	0.51	0.49
			Sig. (2-tailed)	.007*	.009*
	Male (n=23)	PIVA	Pearson Correlation	.360	.254
			Sig. (2-tailed)	.091	.242
		AIVA	Pearson Correlation	0.47	0.46
			Sig. (2-tailed)	.022*	.029*
High	Female (n=30)	PIVA	Pearson Correlation	0.53	0.43
			Sig. (2-tailed)	.002*	.019*
		AIVA	Pearson Correlation	.105	.102
			Sig. (2-tailed)	.582	.590
	Male (n=14)	PIVA	Pearson Correlation	0.68	0.65
			Sig. (2-tailed)	.008*	.012*
		AIVA	Pearson Correlation	.162	.157
			Sig. (2-tailed)	.579	.592

*Significance at 0.05 level

In the low angle 11-15 year old age group (30 subjects) (Table 4): the PIVA was significantly correlated with YA (P =0.007), but not FA (P =0.065). The AIVA in this group was significantly correlated with both YA (P =0.003) and FA (P =0.029).

In the low angle 19-45 year old group (20 subjects) (Table 4): the PIVA was significantly correlated with YA (P =0.023), but not FA (P =0.087). The AIVA in this group was significantly correlated with both the YA (P =0.033) and FA (P =0.011).

Therefore, both the adolescent and adult age groups for the low angle group had significance in the same areas.

Table 4. Correlations by mandibular plane angle and age.

Group				Y-axis	FA
Low	11-15 (n=30)	PIVA	Pearson Correlation	0.48	.341
			Sig. (2-tailed)	.007*	.065
		AIVA	Pearson Correlation	0.53	0.4
			Sig. (2-tailed)	.003*	.029*
	19-45 (n=20)	PIVA	Pearson Correlation	0.51	.392
			Sig. (2-tailed)	.023*	.087
		AIVA	Pearson Correlation	0.48	0.56
			Sig. (2-tailed)	.033*	.011*
High	11-15 (n=26)	PIVA	Pearson Correlation	0.64	0.61
			Sig. (2-tailed)	.000*	.001*
		AIVA	Pearson Correlation	.366	.290
			Sig. (2-tailed)	.066	.150
	19-45 (n=18)	PIVA	Pearson Correlation	0.53	.417
			Sig. (2-tailed)	.023*	.085
		AIVA	Pearson Correlation	-.136	-.090
			Sig. (2-tailed)	.590	.723

*Significance at 0.05 level

In the high angle 11-15 year old group (26 subjects) (Table 4): the PIVA was significantly correlated with both the YA ($P \leq 0.0001$) and FA ($P = 0.001$). The AIVA in this group was not significantly correlated with either the YA ($P = 0.066$) or FA ($P = 0.150$).

In the high angle 19-45 year old age group (18 subjects) (Table 4): the PIVA was significantly correlated with the YA (P =0.023), but not the FA (P =0.085). The AIVA in this group was not significantly correlated with YA (P =0.590) or FA (P =0.723).

Evaluating males and females together, no statistically significant differences were found between age groups for YA, FA, PIVA, or AIVA (Table 5). Evaluating age groups together, there were no statistically significant differences found between measurements for males and females for YA, FA, PIVA, or AIVA (Table 6). Statistically significant differences were found between high and low angle groups when evaluated by male and female groups and by age group for the YA, FA and AIVA, but not for the PIVA (Table 7 and 8).

Table 5. Differences by age category.

	Age Group				Mean Difference	95% CI of the Difference		P-value
	11-15 (N=56)		19-45 (N=38)					
	Mean	Standard Deviation	Mean	Standard Deviation		Lower	Upper	
PIVA	104.6	6.61	104.0	7.02	0.549	-2.280	3.379	0.701
AIVA	117.5	7.59	119.0	8.28	-1.477	-4.764	1.810	0.374
Y-axis	91.6	6.20	91.7	5.72	-0.068	-2.576	2.440	0.957
FA	87.7	6.80	88.8	6.70	-1.102	-3.923	1.719	0.440

*Significance at 0.05 level

Table 6. Differences by gender.

	Gender				Mean Difference	95% CI of the Difference		P-value
	Female (N=57)		Male (N=37)					
	Mean	Standard Deviation	Mean	Standard Deviation		Lower	Upper	
PIVA	104.0	6.64	104.8	6.98	-0.730	-3.572	2.109	0.610
AIVA	118.1	7.51	118.1	8.50	-0.004	-3.320	3.313	1
Y-axis	91.4	5.49	92.0	6.72	-0.655	-3.170	1.861	0.607
FA	87.7	6.27	88.9	7.45	-1.185	-4.017	1.648	0.41

*Significance at 0.05 level

Table 7. One Way ANOVA for gender groups.

	Gender Group								P-value
	Low angle female (N=27)		Low angle male (N=23)		High angle female (N=30)		High angle male (N=14)		
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
Y-axis	96.0	3.28	95.9	3.73	87.3	3.33	85.6	5.54	<0.001*
FA	92.9	3.59	93.3	4.11	83.0	4.01	81.5	5.69	<0.001*
PIVA	105.8	7.05	105.7	6.84	102.5	5.95	103.3	7.19	0.2
AIVA	121.8	5.56	120.8	8.69	114.8	7.54	113.7	6.18	<0.001*

*Significance at 0.05 level

Table 8. One Way ANOVA for age groups.

	Age Group								P-value
	Low angle 11-15 (N=30)		Low angle 19-45 (N=20)		High angle 11-15 (N=26)		High angle 19-45 (N=18)		
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
Y-axis	96.3	2.65	95.4	4.43	86.2	4.39	87.5	3.79	<0.001*
FA	92.9	3.02	93.4	4.81	81.7	4.61	83.7	4.42	<0.001*
PIVA	106.5	7.13	104.7	6.52	102.4	5.28	103.3	7.67	0.13
AIVA	121.5	7.39	121.3	6.87	113.0	4.88	116.5	9.17	<0.001*

*Significance at 0.05 level

Regarding all 94 subjects the mandibular plane angle was found to have a negative correlation with all 4 vectors measured (Table 9).

Table 9. Correlation of mandibular plane angle.

		PIVA	Y-axis	FA	AIVA
Mandibular plane angle	Spearman Correlation Coefficient	-0.28	-0.82	-0.82	-0.49
	Sig. (2-tailed)	.007*	<0.001*	<0.001*	<0.001*

*Significance at 0.05 level

The interclass correlation for the ten retraced cases was high for all variables measured indicating that the investigator was consistent in the identification of planes and landmarks. Interclass correlation for mandibular plane angle was 1.0 (P <0.001). The PIVA, YA and FA all had an interclass correlation of 0.99 (P <0.001). FA had an interclass correlation of 0.96 (P <0.001).

Discussion

The FA and YA were chosen based on their acceptance in the orthodontic literature as vectors of craniofacial growth. The YA is the superimposition used by the American Board of Orthodontics (ABO) to show craniofacial growth over time. Mandibular plane angle of 20° and below was chosen to represent the low angle group as it represented 1.5 standard deviations below the Rickett's normal of 26°. Mandibular plane angle of 32° and above was chosen to represent the high angle group as it represented 1.5 standard deviations above the Rickett's normal of 26°. The 12° difference also ensured good separation of the two groups.

The method of identification for the PIVA and AIVA represent approximations for the slopes of the vomer, but are not the actual slopes. The landmarks chosen to represent the PIVA and AIVA were chosen to improve landmark identification reproducibility and to use points already commonly used by orthodontists. The slopes of the vomer are also not straight lines so using two landmarks allowed for the construction of straight lines that could be more easily correlated with FA and YA.

The null hypothesis was rejected for the AIVA as there was a statistically significant difference between measurements for this vector between high and low angle cases. The null hypothesis was accepted for the PIVA as there was not a statistically significant difference between high and low angle groups.

The PIVA and AIVA both become more obtuse in relationship to the Na-Ba cranial base in low angle cases and become more acute in high angle cases. The AIVA between high and low angle groups has a greater degree of difference than does the PIVA. Correlation between the PIVA with FA and YA was noted in both high and low angle groups. The AIVA was significantly correlated with YA and FA in the low angle group, but not in the high angle group. Evaluating the mean values for the AIVA in high and low angle groups it seems that if the low angle group is correlated the high angle group should be correlated as well. However, due to variation of individual cases in the high angle group a correlation was not found. The lack of correlation between the AIVA with FA and YA may be a result of variability at the junction between the perpendicular plate of the ethmoid and the anterior border of the vomer. The vomer and perpendicular plate of the ethmoid are thin bones which compose the anterior portion of the bony nasal septum. There is a much longer span between larger bones such as the maxilla and palatine bone inferiorly and the body of the sphenoid bone superiorly in the region of the AIVA as opposed to the PIVA. Perhaps the longer span between these larger bones allows for more variation in the AIVA especially in high angle patients who tend to have a longer midface. Another possible explanation is that the anterior slope would be far more likely to be affected by any facial trauma. Nasal septal deviations are common and the anterior portion of the nasal septum would be the first to be affected by trauma. The PIVA, on the other hand, would be more protected due to its more centralized location in the skull.

The possible association of mouth-breathing and vertical facial patterns may also be a reason for variation of the AIVA. In patients with nasal airway constriction the body often compensates by mouth-breathing. This may result in the floor of the nose being lowered as cortical drift takes place. As this occurs the vomer adapts and the values for the PIVA and AIVA decrease. Mouth-breathing is undesirable for facial development as it leads to a facial muscle imbalance that can lead to an increased mandibular plane angle.[16]

Although some of the correlations were stronger for different age groups and genders, there were no statistically significant differences between measurements for age groups or males and females for PIVA, AIVA, YA and FA. Statistically significant differences were found between the high angle and low angle groups for AIVA, YA and FA, but not for PIVA.

The PIVA appears to be less affected by differences in mandibular plane angle since the difference in the mean values for the PIVA between high and low angle groups was 2.9°. However the AIVA had a much larger difference of 6.9°.

It is also interesting to compare the results of the current study to those of the Pulfer study on mesiofacial subjects. He observed a mean value for the PIVA and AIVA of 103.9° and 117.3° respectively[12]. The mean of the measured values for the PIVA and AIVA of all patients, including high and low angle groups, in this study was 104.3° for the PIVA and 118.1° for the AIVA. Therefore, the differences between the mean values for the PIVA and AIVA between the two studies were 0.4° and 0.8° respectively. This shows excellent agreement between the two studies for these measurements.

Mandibular plane angle was found to be negatively correlated with all four vectors evaluated. It is to be expected that as the mandibular plane angle increases the YA and FA decrease as both vectors have reference points on the mandible. However, the PIVA and AIVA do not have reference points on the mandible. Therefore, an approximation of whether a patient has a high or low mandibular plane angle can be determined from an evaluation of the PIVA and AIVA. These two vectors give some insight into the overall facial type of the patient as they were found to have correlations with accepted vectors of craniofacial growth as well as with mandibular plane angle.

The airway is likely a critical factor in the development of the face. Airway obstruction and mouth-breathing as well as the compensatory postures related to maintaining adequate respiration may be associated with a vertical growth pattern.[17] There is likely a difference in the amount of drift and displacement among facial types and dolichofacial patients may experience more cortical drift. This increased drift may be due to the body's attempt to maintain adequate nasal respiration. No published studies were found evaluating nasal airway volume using CBCT imaging as software is in development for accurate evaluation of this region.

For both high and low angle groups the PIVA was significantly correlated with the YA and FA. This correlation is likely due to the effects of both displacement and cortical drift on the PIVA. Therefore, PIVA likely represents a composite vector of both drift and displacement.

The PIVA represents a vector that is composed of two bones; the vomer bone composes the superior 2/3 of the PIVA and the palatine bone composes the inferior 1/3 (Fig 1). The superior 2/3 of the PIVA is a straight segment and likely represents displacement that occurs at a young age. This straight upper portion of the PIVA transitions to a downward curvature in the inferior 1/3 and likely represents cortical drift. The transition from displacement to drift along the anatomical PIVA likely occurs as adjustment at the transverse palatine suture allows the palatine bone to maintain its sagittal position. Preserving the position of the palatine bone posteriorly allows for contact between the soft palate and the pharynx to be maintained for proper speech in the developing face.

According to Scott's nasal septal cartilage theory the perpendicular plate of the ethmoid bone fuses with the vomer at around age 7. [2] Once this fusion occurs, maxillary displacement ceases and cortical drift becomes the predominant mode of maxillary downward and forward growth.

However, the fusion of the perpendicular plate of the ethmoid bone with the vomer bone does not prevent maxillary displacement at other sutures adjacent to the maxilla. The vomer-maxillary suture and the circum-maxillary suture remain patent until skeletal maturity, and therefore allow for continued displacement until approximately age 15 for girls and age 19 for boys. Ranly also states that displacement of the maxilla continues beyond age 7 since point A moves anteriorly concurrently with Na.[8]

Additional support for continued maxillary displacement beyond the age of 7 can be found in the Rickett's lateral cephalometric analysis.[18] Throughout growth the maxillary depth angle, which measures the sagittal position of the maxilla relative to nasion remains constant just as the inclination of Frankfort Horizontal remains constant. In order for this angle to remain constant throughout growth, the maxilla must continue to grow forward as nasion continues to move forward along the Na-Ba plane at a rate of 1mm per year.

The vectors for drift and displacement differ from one another. Displacement occurs in a downward and forward direction, but it appears that drift occurs mostly in a downward direction. A Master's Thesis by Pulfer outlines a method for calculating a vector of facial growth.[12] This method was also used in this study. A perpendicular line to the palatal plane (ANS-PNS) was constructed and the angle it formed with the NaBa cranial base was measured and recorded (Figure 5). This measurement, referred to as the palatal plane perpendicular, represents the vector of cortical drift for the maxilla. According to Bjork's implant studies, displacement represents 43% of nasomaxillary vertical height growth and the remaining 57% is a result of cortical drift.[1]

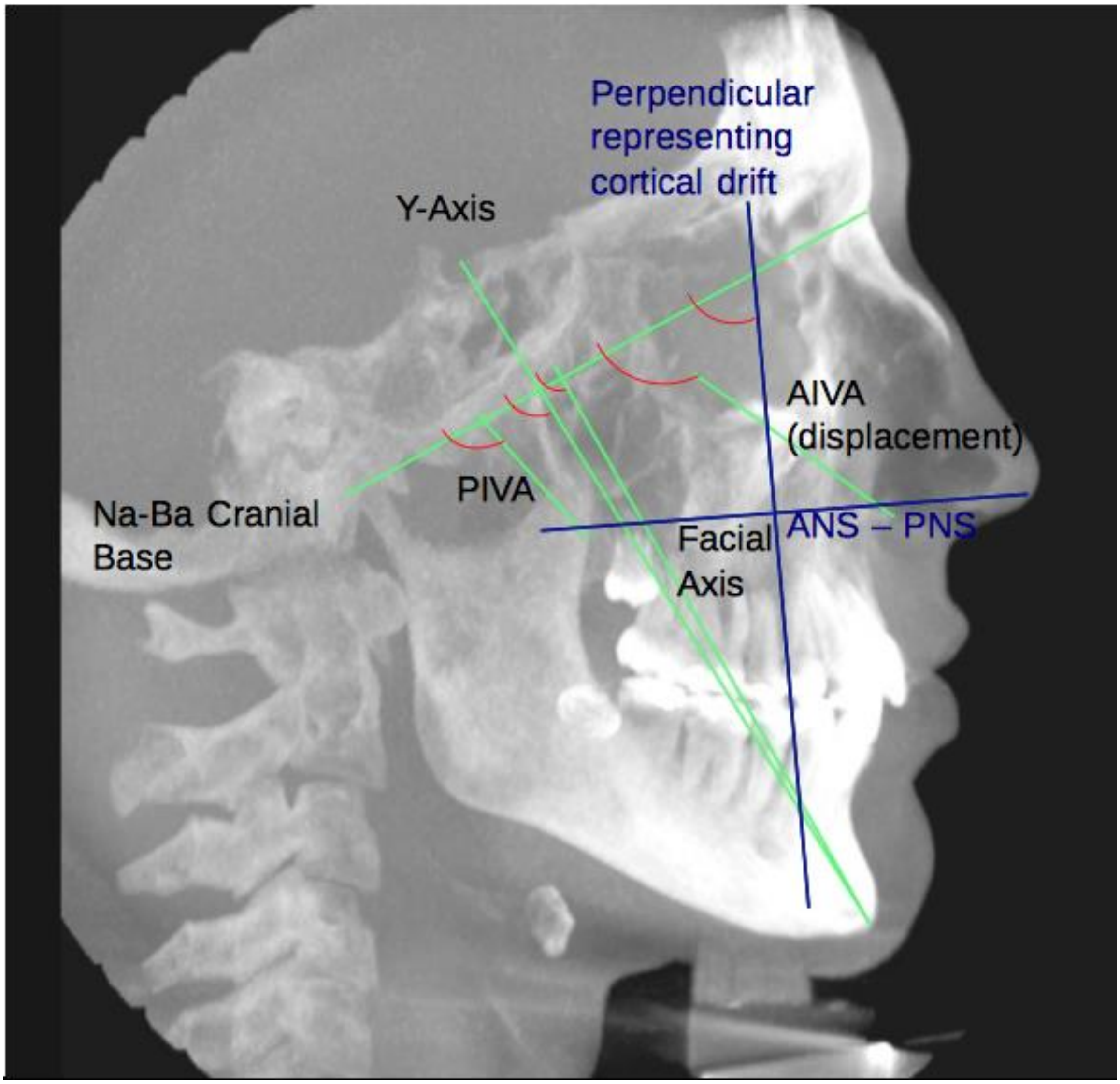

Fig 5. Cortical drift vector shown in blue. The cortical drift vector is drawn perpendicular to the palatal plane (ANS-PNS) shown in blue lines on a CBCT image with reference planes labeled. Na-Ba Cranial Base was the reference plane for measurements of PIVA, AIVA, YA and FA. Red arcs indicate measured angles.

Based on Bjork's percentages of drift and displacement the following formula was used to evaluate the patients in this study: (AIVA) x 0.43 + (Palatal plane perpendicular) x 0.57 = calculated vector of facial growth (CVFG). The AIVA, representing the vector of displacement, is multiplied by Bjork's value for displacement (43%). This value is then added to the vector of cortical drift (palatal plane perpendicular) multiplied by Bjork's value for drift (57%). The CVFG had a statistically high correlation with YA and FA for the low angle groups, but there was no statistically significant correlation for the high angle groups (Table 10).

Table 10. Correlation of CVFG with YA and FA.

Group			CVFG
Low	FA	Pearson Correlation	0.51
		Sig. (2-tailed)	<0.001*
High	FA	Pearson Correlation	.230
		Sig. (2-tailed)	.132
Low	Y-axis	Pearson Correlation	0.51
		Sig. (2-tailed)	<0.001*
High	Y-axis	Pearson Correlation	.240
		Sig. (2-tailed)	.117

*Significance at 0.05 level

Stronger correlation between the CVFG with the YA and the FA was likely found in the low angle group since there was a stronger correlation between the AIVA with YA and FA in the low angle group. The mean value for the CVFG was 84.2° for the high angle group, which is quite close to the observed measurement for FA of 82.5° (Table 11). The low angle group had a mean CVFG of 88.4° and the mean observed measurement for FA was 93.1° (Table 11). The calculation is closer in the high angle cases in this study and Pulfer observed in his study on mesiofacial subjects a difference of 1.5° between the calculated value and observed value. The larger deviation seen in the low angle group is likely due to a larger contribution of displacement than Bjork observed. For example if the contribution of cortical drift and displacement were equal the calculated value would be 92.5°, which is very close to the observed 93°. It is logical to think that there is a difference in the contribution of both drift and displacement in different facial types. Low angle patients may be more likely to be nasal breathers and therefore less drift would be observed than in a high angle patient who may be mouth-breathing in order to meet the demands of respiration.

Table 11. Summary table for palatal plane perpendicular, AIVA, CVFG, FA and PIVA.

			Palatal plane perpendicular		AIVA		CVFG		FA		PIVA	
Group		N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
11 – 15	High	26	60.5	2.917	113.0	4.880	83.1	3.129	81.7	4.613	102.4	5.277
	Low	30	63.8	3.161	121.5	7.387	88.6	4.473	92.9	3.025	106.5	7.135
19 – 45	High	18	62.8	3.246	116.5	9.168	85.9	4.832	83.7	4.420	103.3	7.666
	Low	20	63.1	3.619	121.3	6.870	88.1	4.004	93.4	4.815	104.7	6.518
Males	High	14	60.3	3.185	113.7	6.179	83.2	3.557	81.5	5.690	103.3	7.189
	Low	23	64.3	3.403	120.8	8.694	88.6	5.062	93.3	4.111	105.7	6.839
Females	High	30	62.0	3.151	114.8	7.537	84.7	4.322	83.0	4.011	102.5	5.950
	Low	27	62.9	3.177	121.8	5.563	88.2	3.519	92.9	3.588	105.8	7.050
Composite	High	44	61.4	3.227	114.5	7.079	84.2	4.109	82.5	4.592	102.8	6.295
	Low	50	63.5	3.335	121.4	7.114	88.4	4.257	93.1	3.803	105.7	6.883

Conclusions

The PIVA likely represents a combination vector of both drift and displacement of the maxilla. The AIVA likely represents a vector of maxillary displacement. Low angle patients likely experience more displacement of the maxilla than do high angle patients. High angle patients likely experience more cortical drift of the maxilla than do low angle patients.

CHAPTER THREE

EXTENDED DISCUSSION

Discussion

Genetic and environmental factors all contribute to the overall growth of the face. It is still unclear from the research available if the vomer bone is responsible for some of the displacement of the maxilla or if it is simply an adjustment site. However, it is clear that the PIVA and AIVA correlate with facial type. Low angle patients likely experience more displacement of the maxilla than high angle patients. High angle patients likely experience more cortical drift than low angle patients, likely in the body's attempt to increase nasal airway dimensions in order to maintain adequate respiration.

Further Directions

A future study evaluating the nasal airway dimensions in different facial types would be of great importance to further investigate the relationship between nasal airway and vertical growth pattern. A longitudinal study would also provide great insight, however the radiation required to conduct such a study prohibits it.

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APPENDIX

Raw data								
Group	Case #	Mand plane angle in degrees	PIVA in degrees	YA in degrees	FA in degrees	AIVA in degrees	palatal plane perpendicular in degrees	Calculated value in degrees
High angle female 11-15								
1	179	33	96	82.5	80.5	105	58	78.2
2	97	35	101	86	81	106.5	60	80
3	190	32	101	89	83	120	62	86.9
4	45	37	91.5	85	78	107	61	80.8
5	128	37	101	84	80.5	112	59	81.8
6	108	32	97	89	85	107	56	77.9
7	183	36	105	90.5	87	113	65	85.6
8	37	37	97	82.5	78	108.5	62	82
9	81	32	101.5	87.5	82	116	64.5	86.6
10	154	33	103.5	88	85	111	59.5	81.6
11	92	32	102.5	88.5	86	111	59	81.4
12	136	33.5	103.5	86	79	117	60	84.5
13	2	39	103.5	82	76.5	112	60	82.4
14	43	35	111.5	92.5	88	119	62	86.5
15	54	41	105	88	82.5	111	63	83.6
High angle female 19-45								
1	13	35	99	85	82	121.5	65	89.3
2	122	35	100	88.5	84.5	107.5	60	80.4
3	24	38.5	116.5	94.5	89.5	109.5	61	81.9
4	180	38	107.5	95	92	105.5	70	85.3
5	100	36	100	84	79	110	60	81.5
6	116	35	101	89.5	87	131	68.5	95.4
7	1	36.5	102	90	87	134	61.5	92.7
8	156	34	96.5	86.5	83.5	113	63	84.5
9	186	32	108	88	84	121	63	87.9
10	112	33	104	86	82.5	108	58	79.5
11	165	34.5	116	90	87.5	122	68	91.2
12	71	33	92	86	83.5	118	62	86.1
13	126	33	101	83.5	76	121	64	88.5
14	30	50	111.5	83.5	77	120	62	86.9
15	90	32	100	86.5	82	126	62	89.5

High angle male 11-15								
1	64	32	104.5	87	84	118.5	57	83.4
2	114	35.5	101	86	82	110.5	57	80
3	36	36	114	91	86	117.5	57.5	83.3
4	125	41.5	97	74	69	107.5	57	78.7
5	40	32	101	88	83	117	58.5	83.7
6	204	41	93	75	71	115	62.5	85.1
7	82	32	105.5	92	88.5	111	63	83.6
8	175	39	101.5	85	81	108.5	56	78.6
9	50	34	106.5	87.5	83	120	64.5	88.4
10	173	34.5	107.5	88.5	84	122.5	62.5	88.3
11	16	32	110	86	80.5	114.5	66	86.9
High angle male 19-45								
1	66	32	96	89.5	85.5	98.5	61	77.1
2	89	37	115.5	89.5	87	117.5	61.5	85.6
3	205	39	92.5	80	77	113.5	59.5	82.7
Low angle female 11-15								
1	166	17	114	94.5	90	121	64	88.5
2	138	15.5	100.5	92	85.5	115	57	81.9
3	93	20	108	96	92.5	120	62	86.9
4	10	11	124	103	99	127	66	92.2
5	69	14.5	108	99	95.5	135	69	97.4
6	52	14	110	95.5	92	119	60	85.4
7	55	19	108	100	97	125	61	88.5
8	189	15.5	107	95	91	117.5	64	87
9	17	16	97.5	96.5	94	124	66	90.9
10	14	20	109	95	90.5	122.5	65.5	90
11	88	16	104.5	99	95	122.5	67	90.9
12	86	18	92	95	92	115.5	61	84.4
13	91	15	110	97	95.5	122	64.5	89.2
14	23	18	114	95	90	132.5	65	94
15	181	17	107.5	97	92	126	63	90.1
Low angle female 19-45								
1	172	17	103	96	92	118	61	85.5
2	144	20	100	90.5	90	123	61	87.7
3	141	17.5	110	95	91	122	55.5	84.1
4	67	17	107.5	98	96	124	58	86.4
5	145	20	99	89.5	86	114	60.5	83.5
6	53	20	99	91	89.5	115.5	66	87.3

7	80	12	115	100	97	112.5	62	83.7
8	7	20	96.5	91.5	90.5	115.5	62	85
9	159	15	111.5	101.5	101	130.5	61	90.9
11	174	18	99	97.5	94	121	65	89.1
12	161	13.5	103	95	95	125	64	90.2
13	5	17	98	96.5	94.5	124	66	90.9
low angle male 11-15								
1	150	14.5	105	98	95	111	62	83.1
2	99	18	110	93	90	116	64	86.4
3	83	19	101	93	91.5	106	65	82.6
4	182	19	95	96	94	110	62	82.6
5	21	19.5	108	96	94	121.5	56	84.2
6	87	18	109	98	95	128.5	66.5	93.2
7	29	19	107	93.5	91	123.5	63.5	89.3
8	25	13	104	96	92	126	67	92.4
9	176	12	112	101	98	130.5	67	94.3
10	137	19	91	91	87.5	115	64	85.9
11	164	16	102	95	91	117.5	63.5	86.7
12	148	15	119	98	94.5	121	64	88.5
13	106	19	102.5	98.5	96.5	120.5	65	88.9
14	84	20	103	98	94.5	139	70.5	100
15	98	18	111	95	90.5	113	60	82.8
Low angle male 19-45								
1	95	15	98	93	91.5	113.5	64	85.3
2	170	18	100	91	88	121	64	88.5
3	51	16.5	114	92	88	118	60.5	85.2
4	207	7	115	106	104	120.5	69.5	91.4
5	209	20	110.5	95	92	122.5	62	88
6	27	15	112.5	94.5	93	130	63	91.8
7	18	18	101	92.5	92	114	66	86.6
8	102	12.5	101	102.5	102.5	140.5	71	100.9