ASSOCIATION OF NASAL SEPTUM AREA AND DEVIATION WITH ANTEROPOSTERIOR MAXILLARY POSITION AND FACIAL SKELETAL ASYMMETRIES

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ASSOCIATION OF NASAL SEPTUM AREA AND DEVIATION WITH
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ABSTRACT

During growth of the craniofacial structure, the nasal septum is posited to exert a downward and forward effect on the midface. This phenomena is well documented in vitro and on animals but is still uncertain in humans. This study examined the nasal septum association with craniofacial structures using cone-beam computed tomography (CBCT) of human subjects. First, cartilaginous nasal septum area was tested for association with anteroposterior position of the maxilla. The area of the cartilaginous nasal septum was calculated using the CBCT scan and a lateral cephalometric radiograph was created from the CBCT to evaluate the anteroposterior position of the maxilla. Second, nasal septum deviation was tested for association with frontal skeletal asymmetry. The absolute septal deviation (ASD) was calculated in the frontal plane where most deviated and a frontal cephalometric radiograph was created from the CBCT to evaluate for skeletal asymmetry.

Nasal septum area and anteroposterior position of the maxilla were not associated (bivariate regression analysis, $p>0.05$). Nasal septum area was significantly associated ($p<0.05$) with lower gonial angle, total anterior face height, upper face height, lower face height. Subsequently, a model was created to assess nasal septum area with cranial base

measurements association on the maxillary, mandibular, and maxillo-mandibular measurements (multivariate stepwise regression). This showed a significant association ($p<0.05$) in females for SNA (R^2=23.80%), total maxillary length (R^2=60.80%), and Wits (R^2=14.20%). In males, the model association was significant with total maxillary length (R^2=35.20%), SNB (R^2=31.40%), and ANB (R^2=40.00%).

ASD and skeletal asymmetries were split into right and left deviations and tested for association with right and left measurements, respectively. Right side ASDs had statistically significant ($p<0.05$) correlations with right facial width, right mandibular width, and right occlusal plane. No measurements were significantly associated with left side ASDs and left side measurements.

Though we were unable to test the causal relationship of the nasal septum with facial growth, our results suggest that the nasal septal cartilage may exert a downward force and has minimal forward influence on the midface in humans. It also suggests that a deviated nasal septum may influence the asymmetry of the facial skeleton.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the School of Dentistry have examined a thesis titled "Association of Nasal Septum Area and Deviation with Anteroposterior Maxillary Position and Facial Skeletal Asymmetries," presented by Kevin Kaiser, candidate for the Master of Science degree in Oral and Craniofacial Sciences, and hereby certify that in their opinion it is worthy of acceptance.

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CHAPTER 1

INTRODUCTION

For years, orthodontists, craniofacial biologists, and surgeons have searched for the control center of craniofacial growth. If one principal growth center was identified, then manipulation and modification of this growth center could be used to treat growth disorders. Orthodontists in particular have a vested interest in understanding the normal growth process as they strive to treat patients to have an ideal occlusion, well–aligned jaws, and an overall pleasing facial esthetic. The development of the hard and soft tissues surrounding the jaws are important in terms of understanding their influence on the jaws and midface to achieve clinically acceptable outcomes. It is estimated that approximately 15% of patients develop class II malocclusion and 1% develop class III malocclusion (Proffit et al. 1998), but the precise mechanism causing these malocclusions is still unknown.

A Review of Craniofacial Bone Ossification

To understand how growth occurs, it is necessary to have knowledge of the structures associated with the craniofacial complex. The craniofacial skeleton is often grouped into sub–units: the desmocranium, the chondrocranium, and the splanchnocranium. The desmocranium arises from the ectomeninx embryonically, which forms to surround the brain during very early growth. Growth of these skeletal bones takes place purely from intramembranous ossification. The chondrocranium, like the desmocranium, is also derived from the ectomeninx embryonically, but differs in that it uses endochondral ossification to form the bones of the cranial base. The splanchnocranium, or viscerocranium, arises from the first branchial arch embryonically to form the bones of the midface and mandible through intramembranous ossification. While these units are separate from their embryological origin or by the process of ossification, they combine to make up the neurocranium (the desmocranium plus part of the chondrocranium) and the face (part of the chondrocranium and the splanchnocranium) (Carlson and Buschang 2011).

Ossification of the Neurocranium

The neurocranium of the skull surrounds the brain and is composed of the cranial base and vault. The cranial base includes the sphenoid and ethmoid bones, as well as a portion of the anterior occipital bone known as the basioccipital bone, and a portion of the frontal bone and temporal bone at the midline (Nie 2005). The function of the cranial base is to support the brain and organs such as the pituitary gland (Wei et al. 2016). The anterior cranial base is derived from neural crest cells, but the posterior cranial base is derived from paraxial mesoderm cells (Couly et al. 1993; Le Douarin et al. 1993). Formation of the entirety of the cranial base is accomplished through endochondral ossification of a cartilage intermediate derived from condensed mesenchymal cells (Bernard et al. 2015; Blaser et al. 2015; Wei et al. 2016). Because of its endochondral development, the cranial base is referred to as the chondrocranium. Ossification of the chondrocranium is progressive with age and takes place in a caudal to rostral direction (Mao and Nah 2004), with initiation from numerous ossification centers (Nie 2005). Well–organized bands of cartilaginous structures known as synchondroses remain between the occipital and sphenoid bones as well as the sphenoid and ethmoid bones (Mao and Nah 2004). Acting as bipolar growth plates, these synchondroses remain cartilaginous and are active as areas of growing cartilage (Proffit 2007) that contribute significantly to the overall postnatal lengthening of the cranial base (Ma and Lozanoff 1999; Nemzek et al. 2000; Jeffery 2002; Jeffery and Spoor 2004).

Ossification of the Viscerocranium

The fourteen facial bones, collectively known as the viscerocranium, include the paired zygomatic, palatine, nasal, maxillary, lacrimal, and inferior nasal concha, and the unpaired mandible and the vomer. Unique from that of the neurocranium, development of the viscerocranial bones depends on migration of neural crest cells from the forebrain and midbrain to interact with the first pharyngeal arch of the developing embryo. These neural crest cells form the mesenchyme that is ossified intramembranously for the majority of facial bones, with the exception of portions of the developing mandible (Sperber 2006; De Coster et al. 2007). Particularly important in the facial development is the contribution of the nasal septal cartilage from the chondrocranium.

The mandible is formed by a combination of both intramembranous and endochondral ossification. Initially, the mandible develops from the template of Meckel's cartilage of the ventral portion of the first pharyngeal arch (Lee et al. 2001), but this cartilage is not replaced by bone (Sperber 2006). Rather, the primary site of intramembranous ossification, which forms the body of the mandible, is located adjacent to the bifurcation of the inferior alveolar nerve into the incisive and mental nerves. Ossification then spreads in both an anterior and posterior direction (Sperber 2006). At approximately 10–14 weeks, secondary cartilages appear at the eventual head of the mandibular condyle, the coronoid process, the symphysis, and the angle of the mandible. These sites of cartilage undergo endochondral ossification and eventually fuse with the intramembranous body. The cartilage of the mandibular condyle, which consists of both type I and type II cartilage, is unique as a secondary cartilage because it develops without the need for any mechanical perturbation, although it does require some form of mechanical stimulation to continue to grow and add to the overall length of the developing mandible (Mao and Nah 2004; Sperber 2006).

The maxillary process forms from the dorsal portion of the first pharyngeal arch following the induction of the mandibular process. The center of mesenchymal condensation in the maxillary process is located on the lateral surface of the nasal capsule (Proffit 2007). Following initial ossification of the mandible, primary bilateral intramembranous ossification centers are formed for the remaining bones of the viscerocranial skeleton (Sperber 2006). The right and left maxillary bones begin their ossification at sites adjacent to the end of the infraorbital nerve, and then paired bilateral secondary zygomatic, orbitonasal, and nasopalatine sites of ossification form. Ossification continues intramembranously, and bone is added through apposition at sutures connecting the maxilla and other small bones of the viscerocranium to the cranial base (Carlson and Buschang 2011).

Theories of Craniofacial Growth

Over the years, craniofacial biologists have postulated many theories of craniofacial growth. The first theory to become popular was the remodeling theory. It proposed that bone grows appositionally at surfaces and the jaws grow by deposition of bone at the posterior surfaces of the maxilla and mandible. In the remodeling theory, sutures played little or no role in the regulation of growth.

In contrast to the remodeling theory, the sutural theory brings sutures to the forefront and claims that the connective tissue and cartilaginous joints are the primary location of growth. It also claims that the proliferation of the circum-maxillary suture system causes the midface to grow downward and forward.

The nasal septum theory came about because the previous two theories still seemed incomplete. According to this theory, sutures play little to no direct role in growth of the craniofacial skeleton but rather have a secondary, or compensatory role. The nasal septum acts prenatally and early in the postnatal period until around three to four years old by anterior–inferior growth of nasal septal cartilage which is “buttressed” against the cranial base posteriorly and pushes and directs the midface downward and forward. This separates the sutures between the premaxilla, the maxilla, and the palatine bones and bone fills in the separated suture sites allowing growth to occur. Cartilage in the mandibular condyles acts similarly to the cranial base and nasal septal cartilage by pushing the mandible downward and forward.

The functional matrix hypothesis brings the surrounding environment into play. It incorporates epigenetics and says that bones grow secondarily to the soft tissues and respond with growth to support them.

The servosystem theory is characterized in two ways: (i) the hormonally regulated growth of the midface and anterior cranial base and (ii) the rate limiting step of this growth on the growth of the mandible. Essentially, the forward growth of the maxilla causes changes in the occlusion which promotes condylar growth of the mandible (Carlson 2005).

While all of these theories have some truths to them, they each only tell a small portion of the entire story. Currently, there is a consensus in the orthodontic community on the process by which certain aspects of the cranium grow. It is understood that the cranial vault continues to grow postnatally at the sutures with the growth of the brain the principle driving force in the increase in size until they close towards the end of the second decade of life (Carlson and Buschang 2011). The cranial base grows postnatally due to the synchondroses between the sphenoid and basioccipital bone as well as the sphenoid and ethmoid bones. These synchondroses are akin to the growth plates in long bones in that the growth is not usually affected by environmental factors because cartilage does not have a blood supply that would allow signaling molecules from the local environment to influence the chondrocytes (Spears and Svoboda 2005). The postnatal lengthening of the midface occurs until the sphenoethmoidal synchondrosis fuses around age seven and the spheno–occipital synchondrosis fuses after puberty ends.

The midface, including the nasal septum and maxilla, undergoes a complex remodeling process postnatally. While it is well developed at birth, it is small in proportion to the cranial base and vault. The circum-maxillary and inter-maxillary sutures are sites of active bone growth, while the nasal capsule and nasal septum are still primarily cartilaginous and continuous with the anterior cranial base. The interstitial cartilaginous growth of the nasal septum helps drive the midface anteriorly and inferiorly. This growth of the septum helps split the sutures in the maxilla and promote bone growth. While growth of the premaxilla/maxilla suture closes between ages three to five normally (Behrents and Harris 1991), the midpalatal and transpalatal sutures do not close until approximately ages 15–18 radiographically (Melsen 1975). The midpalatal and transpalatal sutures are important in the anteroposterior and transverse growth of the maxilla. As the midface is displaced anteriorly, the maxilla responds with bony growth at the posterior margin of the maxillary tuberosity, resulting in an increased length of the maxilla and dental arch (Enlow and Bang 1965). The overall inferior displacement results from a combination of orbital floor displacement superiorly and nasal floor displacement inferiorly (Björk and Skieller 1976; Bjork and Skieller 1977). As the midface is displaced anteriorly and inferiorly, nasion also grows anteriorly at a similar rate so the sella–nasion–A–point angle (SNA) stays relatively consistent after age four (Carlson and Buschang 2011).

The mandible is proportionally the least developed at birth. It follows the growth of the midface in a downward and forward fashion. Traditionally, the condylar cartilage was viewed as the growth center of the mandible. Now, it is realized that mandibular growth is much more complex and that there is not a single gene that codes for the control of condylar growth. The ramus is very important morphologically to the growth of the mandible as it undergoes significant remodeling and has multiple muscle attachments to it which help contribute to growth pace making for the mandible to keep it in occlusion with the maxilla. As there is a variability in each patient's growth of the nasomaxillary complex, the mandible has to be adaptive to fit the facial profile of that patient (Enlow and Hans 2008c).

The growth of all the components of the craniofacial complex are interrelated and have effects on each other. The cranial base generally controls most displacements and rotations of the maxillomandibular complex through epigenetics from the cartilaginous growth of the chondrocranium. As the superior portions of the synchondrosis have greater chondrogenesis, the cranial base angle decreases and this can control the rotation and displacement of the splanchnocranium (Enlow and Hans 2008a). Ultimately, this can affect whether a patient will develop to be retrognathic or prognathic. The nasal septum within the midfacial complex is known to play an important role in the displacement and rotation of the nasomaxillary complex, but it is thought to have a very limited effect after seven to eight years of age (Carlson and Buschang 2011). Finally, the mandible is greatly influenced by the growth of the nasomaxillary complex (Lavergne and Petrovic 1983).

The Nasal Septum as the Pacemaker for Midfacial Growth

Many studies have looked into the nasal septum and its potential to be a growth center or a pacemaker for growth. It is known that the nasal cartilage growth occurs in adolescence until about 16 years of age or older for females and 17 years of age or older for males (van der Heijden et al. 2008). While not yet fully understood if the nasal septum is acting in a causal manner, there is considerable evidence, including some landmark studies, that suggests the nasal septal cartilage acts as the growth center of the midface (Sarnat and Wexler 1966; Sarnat and Wexler 1967; Sarnat 2008). The first study by Sarnat and Wexler explores the gross removal of structures in the midface of rabbits, including the entire bony and cartilaginous septum. In less than two months, the rabbits had a lack of growth of the snout compared to operated and non–operated on controls. Sarnat and Wexler repeated the study but removed only the nasal septal cartilage (no bone removed) surgically. In this study they found similar results to their initial study with gross removal of the septum, indicating that the nasal cartilage plays a major role in the growth of the snout in rabbits. (Sarnat and Wexler 1966; Sarnat and Wexler 1967). In a review of his studies, Sarnat remarked how lack of growth was only limited to the snout anterior to that region and the degree of change directly correlated with the amount of septum resected (2008). Considering the nasal septum theory outlined previously, researchers postulate that the mechanical force of the nasal septum pushing from the cranial base promotes separation of the facial sutures. The mechanical pushing from the expansion of the nasal septum, resulting from the interstitial cartilage growth and endochondral ossification at the perpendicular plate of the ethmoid, helps drive the midface downward and forward (Copray 1986; Wealthall and Herring 2006).

In this regard, the nasal septum is acting as a growth plate or growth center that controls the overall growth of the midface.

If the nasal septum does indeed act as a growth center for the midface in humans, then excessive growth of the nasal cartilage or any deviations arising during its growth would elicit effects on the surrounding structures. Multiple studies have documented the correlation between nasal septal deviation and asymmetries of the external nose (Gray 1983; Reitzen et al. 2011), yet this has not been studied to the same degree with the internal bony structures. It has also been shown that the inferior turbinate bone and corresponding mucosal layers hypertrophy consistently on the concave side of a nasal septal deviation (Berger et al. 2000; Egeli et al. 2004). In addition, external facial asymmetries beyond the nose have been documented. Surgeons have come to understand the importance of nasal septal repair when injury or pathology occurs to achieve normal midfacial growth. Cleft lip and palate patients present with this phenotype as the nasolabial muscles on the non–cleft side will pull the nasal septum causing lateral bending and deviation. If left unrepaired, facial asymmetry will result as the nasal septum pushes on the anterior nasal spine and will worsen over time during growth (Hall and Precious 2013). With intervention however, repositioning of the nasal septum and muscles back to the midline will allow a more normal growth pattern to occur (Smahel et al. 1999). Studies of twins have shown that anterior septal deformities have resulted in shorter anteroposterior lengths of the maxilla (Grymer et al. 1991). A case report of a twin developing nasal septal destruction that required removal at age seven developed a saddle nose with upward displacement of the maxilla and a retrognathic maxilla due to decreased anteroposterior maxillary growth (Grymer and Bosch 1997). Yao et al. determined that there is a relationship between nasal axis deviation and lower midface asymmetries

(2009). Kim et al. in 2011 found that a deviated septum was correlated with a horizontal facial asymmetries when looking at two–dimensional photographs (2011).

Recently, a proposal was made to standardize the classification of nasal septal deviations and methods to study them. Because of the three–dimensional makeup and multiple planes that deviation can occur in, studying the nasal septum and surrounding structures has been challenging. Now that three–dimensional imaging technology is readily available and at a low dose of radiation to patients, it is frequently becoming the diagnostic imaging of choice for clinicians. This has allowed researchers to analyze data in multiple planes with no distortion or magnification (Ludlow et al. 2007; Kamburoglu et al. 2011). One recent study examined the role of deviations in the nasal septum to see how it affects the development of surrounding skeletal structures and resulting facial asymmetries. While they found no correlation between septal deviation and overall magnitude of facial asymmetry, there was an association with asymmetry in the nasal floor and palatal regions. This correlation did not extend to the lateral facial skeleton, but does highlight the role the nasal septum may play in normal development of its surrounding structures (Hartman et al. 2016).

While some studies suggest that the nasal septum acts as a primary growth center in humans, it is still not fully understood due to the difficult nature of producing a reliable animal model which can translate to humans. There have been many studies to date examining the nasal septum and its effect on surrounding structures in an anteroposterior view, but these studies have used the relative amount of deviation present as their principle measurement instead of the absolute amount. In addition, surprisingly little information exists in the current literature of the effect the nasal septum exerts on structures in the front plane, particularly related to symmetrical growth of the maxilla in humans.

When orthodontically diagnosing a patient, a cephalometric analysis is performed. The position of the maxillary unit is often measured in relation to the cranial base by the sella–nasion–A point angle (SNA). This angle can tell the practitioner the relative prognathism of the maxilla in relation to the cranial base. A similar measurement is used to describe the mandibular position (SNB) and the difference between these angles (ANB) is useful to describe the relationship of the mandible to the maxilla.

Problem Statement

The purpose of this retrospective study will be two–fold. Using Cone–Beam Computed Tomography (CBCT), first, we will examine the area of the cartilaginous nasal septum and its effect on the position of the maxilla in a lateral view correlating to skeletal malocclusions. The second goal is to examine, from a frontal view, the effect of nasal septum deviation and if there are any asymmetries in the maxilla correlated to the absolute amount of deviation present.

Hypotheses

1. There will be a correlation between cartilaginous nasal septum area and anteroposterior position of the maxilla.
2. There will be a correlation between absolute nasal septum deviation and skeletal asymmetry

CHAPTER 2

MATERIALS AND METHODS

Access of Cone–Beam Computed Tomography (CBCT) Records

The CBCT scans required for this study were procured from the private practice of a University of Missouri–Kansas City, School of Dentistry (UMKC) Oral Radiology Faculty member. All CBCT images were de–identified, as per the coded agreement, prior to the commencement of the study by the UMKC Oral Radiology Faculty. All attempts were made to only include the CBCT scans of subjects who have completed nasal cartilage growth before the CBCT was taken, but to increase the sample size subjects 15 years and older were included. Any CBCTs taken with incomplete or inadequate field of view as well as any obvious pathology were excluded from the study. UMKC Oral Radiology faculty collected 46 CBCTs from the archives that meet the inclusion/exclusion criteria with equal distribution of males and females.

Measuring Cartilaginous Nasal Septum Area

A board certified oral and maxillofacial radiologist measured the area of the nasal septum cartilage using an imaging software program[1]. The anatomical boundary used to measure the area of nasal septal cartilage is defined superiorly by the nasal bone, posteriorly by the perpendicular plate of the ethmoid bone and vomer bone, inferiorly by the maxillary bone, and anteriorly by the membranous septum (alar cartilage) (Norton and Netter 2012). Using the imaging software, the outline of the cartilaginous nasal septum anatomical boundary was delineated, as described above, in sagittal view at a CBCT scan thickness of

[1] Invivo, Anatomage, San Jose, CA, 95110

2.5mm. Based on the delineated boundary, the imaging software calculated the area of nasal septum cartilage in millimeter^2 (fig. 1). The cartilaginous nasal septal area was measured twice on each image by the trained oral radiologist and the average was computed.

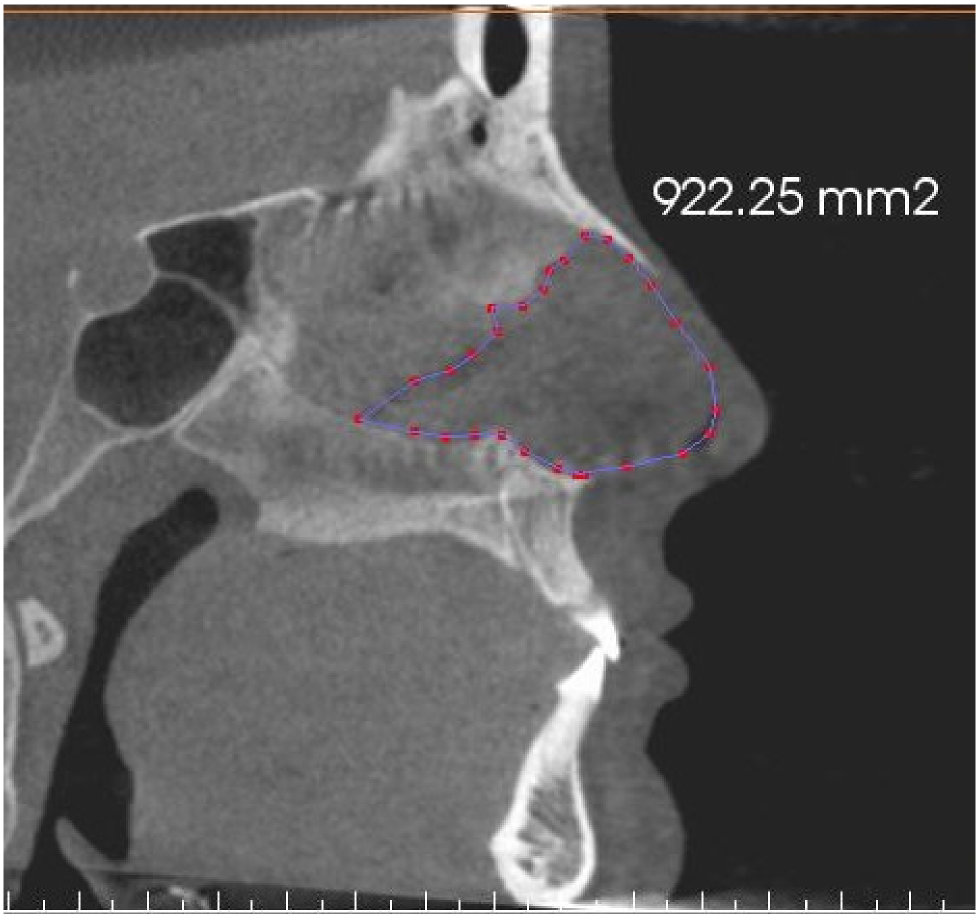

Figure 1. Example measurement of the nasal septum cartilage. The boundaries are described in the text.

Measuring Nasal Septum Deviation

The board–certified oral and maxillofacial radiologist generated de–identified images, in the coronal section, where the nasal septum is most severely deviated. In this image, the nasal septum deviation was measured in absolute degrees of deviation. A vertical line extending from crista galli through anterior nasal spine (ANS), henceforth known as the midsagittal plane, was used as the vertical reference plane. The image was then oriented so that the midsagittal plane is parallel to the true vertical plane. The resulting image was printed in a 1:1 ratio and the angle of septal deviation (ASD) measured in degrees from the midsagittal plane to the most deviated point of nasal septum with a protractor (fig. 2). The ASD was measured three times for each image with the average computed and intra–observer reliability was computed prior to data collection for the reliability of the measurements. The septal deviation to the subject's left was recorded as positive (+) degree (^{o}) measurement and to the right was recorded as negative (–) degree (^{o}) measurement.

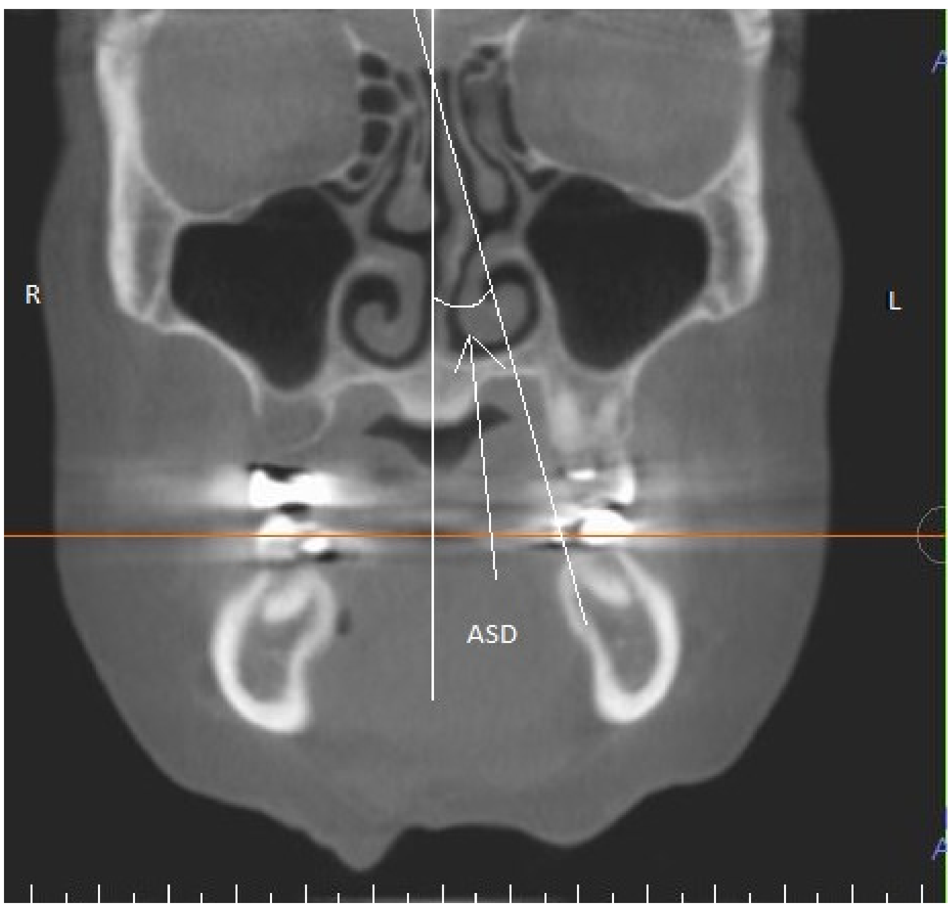

Figure 2. Example measurement of the nasal septum deviation. Deviation to subject's left is recorded as a + degree measurement and to the right as – degree measurement.

Creation of Lateral and Frontal Cephalograms

The board–certified oral and maxillofacial radiologist generated de–identified images of right lateral and frontal (postero–anterior) cephalograms from the selected CBCT scans that met the inclusion/exclusion criteria. The generated lateral and frontal cephalograms were created in an orthogonal projection to minimize the radiographic distortion. These cephalograms had a 100 millimeter scale bar that will be used as reference for lateral and frontal cephalometric analyses. The de–identified right lateral and frontal cephalograms were uploaded to different imaging software[2] for cephalometric analyses.

Measurement of Lateral Cephalograms

The anatomical landmarks for the analyses of anteroposterior maxillary position (Hypothesis 1) were identified on each lateral cephalogram as previously described (Yen 1960). Using these landmarks, linear and angular measurements as adopted from the analyses of McNamara (1984), Steiner (1953), Jacobson (1975), and Ricketts (1981) were utilized to evaluate the position of maxilla. These measurements are:

1. Anteroposterior position of the maxilla relative to the cranial base (SNA measured in degrees)
2. Anterior position of the maxilla (Pt. A in figure 3 to Na Perp measured in millimeter)
3. Palatal Plane Angle (PP-FH measured in degrees)
4. Anteroposterior position of maxilla relative to the forehead (Lande's angle measured in degrees)

[2] Dolphin Imaging Version 11.9.7.20, Chatsworth, CA 91311

5. Total maxillary length (Co–Pt. A measured in millimeters)

In addition to the aforementioned linear and angular measurements, other cephalometric measurements were recorded to characterize the CBCT images used in this study. These additional measurements are described in table 1. To determine the skeletal classification of the study population ANB angle was used and defined as: skeletal class I ANB between 0° and 3.5°, skeletal class II ANB greater than 3.5°, and skeletal class III less than 0° (Proffit 2007). The lateral cephalometric measurements were recorded three times with the average being computed for each value and intra–observer reliability was computed prior to data collection. An example of a traced lateral cephalogram and the angular and linear measurements recorded in this study is shown in figure 3.

TABLE 1

LATERAL CEPHALOMETRIC MEASUREMENTS

Region	Measurements (angular and linear)	Definition
Cranial Base	SN–FH (°)	Cranial vault to Frankfort Horizontal plane angle
	S–N (mm)	Anterior cranial base length
	S–Ba (mm)	Posterior cranial base length
	N–S–Ba (°)	Cranial base angle
	N–Ba/FH (°)	Cranial base flexion
Maxillary Skeletal	SNA (°)	Anteroposterior (AP) position of the maxilla relative to the cranial base
	Pt A to N (⊥FH) (mm)	AP position of maxilla relative to Frankfort Horizontal
	PP–FH (°)	Palatal Plane Angle
	Lande's angle (°) (FH/N–A)	AP position of maxilla relative to the forehead
	Co–Pt A (mm)	Total maxillary length
Mandibular Skeletal	SNB (°)	AP position of the mandible relative to the cranial base
	Pog–Na perp (mm)	AP position of the mandible from Nasion
	Facial angle (°)	AP position of the mandible relative to Frankfort Horizontal
	Go–Gn (mm)	Mandibular body length
	Co–Gn (mm)	Total mandibular length
	Ar–Go (mm)	Ramus height
	Ar–Go–Me (°)	Gonial angle
	Ar–Go–N (°)	Upper gonial angle
	N–Go–Me (°)	Lower gonial angle
Maxillary / Mandibular	FMA (°)	Frankfort Horizontal relative to Mandibular plane
	MP/SN (°)	Mandibular plane angle
	ANB (°)	Sagittal intermaxillary relationship
	Wits (mm)	Sagittal intermaxillary relationship
	Mx–md diff (mm)	Maxillomandibular differential
	Molar relation (mm)	Upper first molar to lower first molar distance
Vertical	SN/S–Gn (°)	y–axis angle
	N–Me (⊥FH) (mm)	Total anterior face height
	Nasion to ANS (mm)	Upper face height
	ANS to Me (mm)	Lower face height
	LAFH ratio (ANS–Me/N–Me)	Percentage of lower anterior face height to total anterior face height

Table 1 Continued

Region	Measurements (angular and linear)	Definition
Vertical	UFH/LAFH ratio	Percentage of upper to lower face height
	S–Go (⊥FH) (mm)	Total posterior face height
	S–Go/N–Me (%)	Posterior face height/anterior face height ratio
Vertical Dentoalveolar	U1–ANS (mm)	Upper incisor vertical distance from ANS
	U6–PP (mm)	Upper first molar vertical distance from palatal plane
	L1–Me (mm)	Lower incisor vertical distance from menton
Sagittal Dentoalveolar	U1–Pt A (V) (mm)	Anteroposterior position of upper incisors
	U1–SN (°)	Maxillary incisor angle
	IMPA (°)	Mandibular incisor angle
	FMIA (°)	Frankfort mandibular incisal angle
	L1–A Pog (mm)	Lower incisor anteroposterior position
	Interincisal angle (°)	Angle between long axes of upper and lower incisors

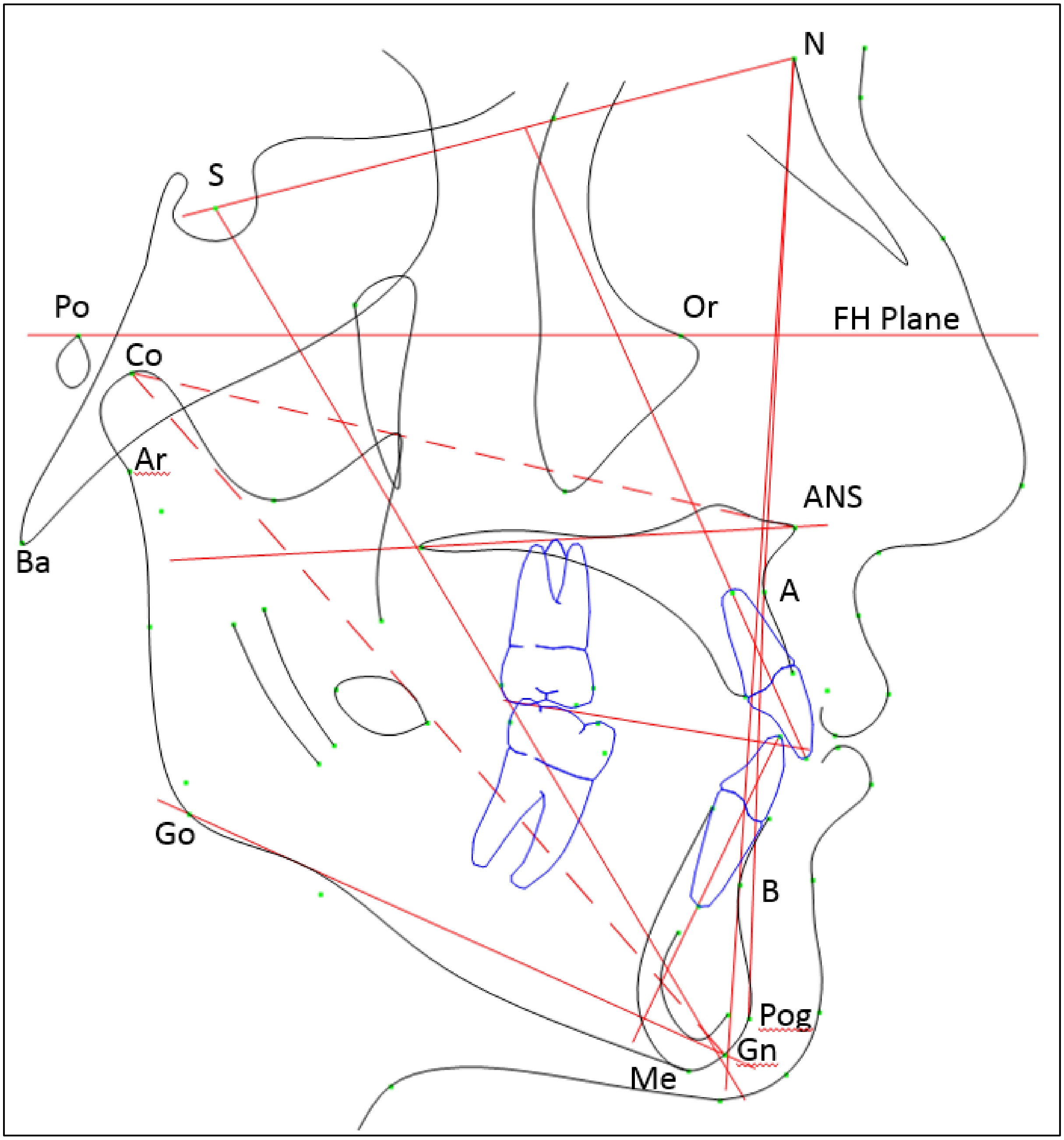

Figure 3. Example tracing of Lateral Cephalogram. Legend: S – Sella; N – Nasion; Po – Porion; Or – Orbitale; FH – Frankfort Horizontal plane; Co – Condylion; Ar – Articulare; Ba – Basion; ANS – Anterior Nasal Spine; A – A–point; B – B–point; Go – Gonion; Pog – Pogonion; Gn – Gnathion; Me – Menton

Measurement of Frontal Cephalograms

The anatomical landmarks for the analyses of skeletal asymmetries (Hypothesis 2) were identified on each frontal cephalogram as previously described (Yen 1960). The transverse measurements to evaluate the skeletal asymmetry were adopted from Ricketts (1982) and Snodell (1993) (table 2). For each frontal cephalogram, the midsagittal plane (bisects crista galli, anterior nasal spine, genial tubercles in symmetric face) was generated and oriented to the true vertical plane. Subsequently, the transverse measurements were recorded as a total distance (in millimeters) as well as left and right side measurements (in millimeters) from the midsagittal plane. The transverse measurements used to evaluate the skeletal asymmetry in this study are:

1. Facial width (distance in millimeter from left to right zygomatic arch)
2. Nasal width (distance in millimeter at widest part of the nasal cavity measured in millimeters)
3. Maxillary width (Distance in millimeter from bilateral points on jugal process where tuberosity and zygoma intersect)
4. Mandibular width (distance in millimeter from left to right gonial angle)
5. Maxillary intermolar width (distance in millimeter from buccal surface left to right maxillary first molars)
6. Mandibular intermolar width (distance in millimeter from buccal surface of left to right mandibular first molars)

In addition to transverse measurements, vertical measurements were recorded as described in table 2 to characterize the CBCT images used in this study. The frontal cephalometric measurements were recorded three times with the average being computed for each value and intra–observer reliability was computed prior to data collection. An example of a traced frontal cephalogram and the transverse linear measurements recorded in this study is shown in figure 4.

TABLE 2

FRONTAL CEPHALOMETRIC MEASUREMENTS

	Measurements	**Description**
Transverse measurements (OVERALL, Right and Left from Midsagittal plane) (all mm unless noted)	Facial width (bizygomatic width) (mm)	Distance from left zygomatic arch (ZA) to right zygomatic arch (AZ)
	Nasal width (bialare width) (mm)	Distance at widest part of nasal cavity
	Maxillary width (mm)	Distance from bilateral points on jugal process where tuberosity and zygoma intersect
	Mandibular width (bigonial width) (mm)	Distance from left gonial angle to right gonial angle
	Maxillary intermolar width (6–6) (mm)	Distance from buccal surface of the maxillary left first molar to the buccal surface of the maxillary right first molar
	Mandibular intermolar width (6–6) (mm)	Distance from buccal surface of the mandibular left first molar to the buccal surface of the mandibular right first molar
Vertical measurements	Right ramus height (mm)	Distance between right gonial angle and most superior right aspect of the condyle
	Left ramus height (mm)	Distance between left gonial angle and most superior left aspect of the condyle
	Occlusal Plane (OP) tilt (mm)	Difference in height between OP and ZL–ZR plane
	OP cant (°)	Angle between OP and line drawn perpendicular to the midsagittal plane

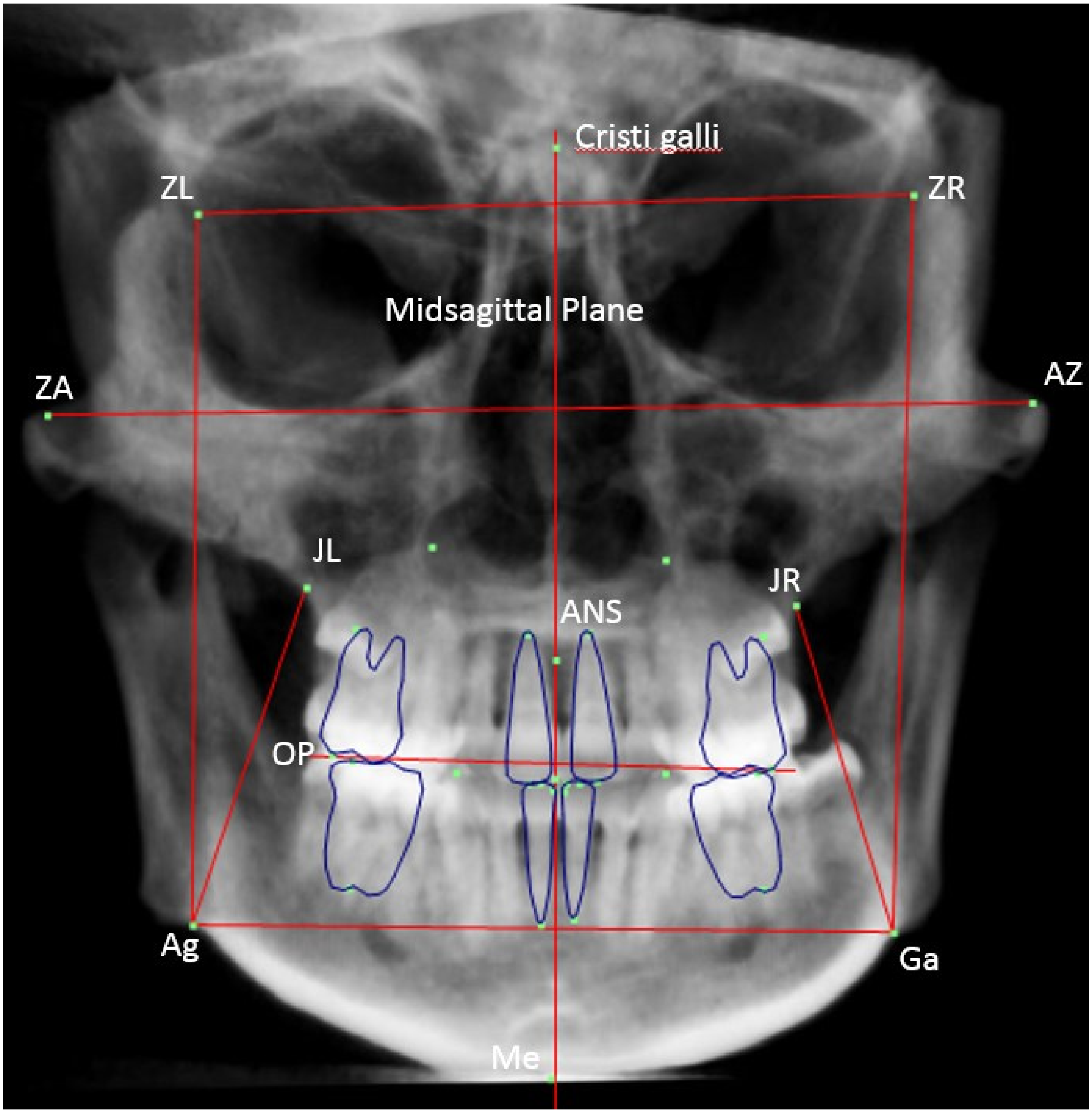

Figure 4. Example tracing of Frontal Cephalogram. Legend: ZL – Left zygomaticofrontal suture; ZR – Right zygomaticofrontal suture; ZA – Left zygomatic arch; AZ – Right zygomatic arch; JL – Left jugal process where tuberosity and zygoma intersect; JR – Right jugal process where tuberosity and zygoma intersect; ANS – Anterior Nasal Spine; OP – Occlusal plane; Ag – Left gonial notch; GA – Right gonial notch; Me – Menton

Experimental Design and Sample Size

This cross–sectional single observer study was performed on archived CBCT scans from the private practice of a University of Missouri–Kansas City, School of Dentistry (UMKC) Oral Radiology Faculty member. This study protocol was reviewed and approved by the UMKC Institutional Review Board (#17–115). The convenient sample size of this study is 46. The sample size was in part determined based on a recently published manuscript reporting significant outcome metrics using a similar sample size (Hartman et al. 2016). This study had two major hypothesis with an experimental design to examine the association between (i) the area of the cartilaginous nasal septum and the anteroposterior position of the maxilla, and (ii) the deviation of the nasal septum and skeletal asymmetry (table 3).

TABLE 3

EXPERIMENTAL DESIGN

	Independent Variable	**Dependent Variable**
Hypothesis 1	Cartilaginous Nasal Septum Area (mm^2)	Anteroposterior position of maxilla-linear measurements (mm) and angular measurements (^{o})
Hypothesis 2	Absolute Nasal Septum Deviation (^{o})	Skeletal asymmetry of maxilla-linear measurements (mm)

Data Analyses

The data procured in this study was analyzed using a statistical software program[3]. First, the collected data was tested for normality and population demographics were defined. Box plots were created to visualize the distribution of the data between groups. To test hypothesis 1 we evaluated for the presence of statistically significant ($\alpha \leq 0.05$) associations

[3] StataCorp Stata Statistical Software Version 15.1, College Station, TX 77845

between the nasal septum cartilage area and lateral cephalometric measurements using bivariate regression analysis. We also tested for a significant interaction between genders to see if there were any differences between males and females.

Further, a multivariate stepwise regression analysis was performed. In the step–wise regression model, the squared multiple correlation coefficient (R^2, ranging from 0 to 1) was computed to explain the predictability of the independent variables on the dependent. The model predictors (independent variables) were:

1. Septal area
2. Anterior cranial base (S–N in mm)
3. Posterior cranial base (S–Ba in mm)
4. Cranial base angle (N–S–Ba in degrees)

The outcomes (dependent variables) assessed using this model were:

1. Average anteroposterior position of the maxilla relative to cranial base (SNA) (in degrees)
2. Maxillary skeletal position (Pt A to Na ⊥ in degrees)
3. Maxillary depth (Lande's angle FH/N–A in degrees)
4. Total maxillary length (Co–Pt A) (in mm)
5. Anteroposterior position of mandible to cranial base (SNB) (in degrees)
6. Anteroposterior position of mandible from nasion (Pog–Na) ⊥ (in mm)
7. Total mandibular length (Co–Gn) (in mm)
8. Sagittal intermaxillary relationship (ANB) (in degrees)
9. Sagittal intermaxillary relationship (Wits) (in mm)
10. Maxillo-mandibular differential (Mx–Md difference) (in mm)

The cranial base measurements (anterior cranial base, posterior cranial base, and cranial base angle) were chosen as model predictors because the cranial base growth contributes to the secondary displacement of nasomaxillary complex in anterior and inferior direction (Enlow and Hans 2008b). Our outcome variables were chosen as they are commonly used clinically when diagnosing and treating a case orthodontically and would be clinically relevant to assess maxilla and mandibular position along with maxillo–mandibular relationship. The model was split up by gender to test for significance.

To test hypothesis 2, we evaluated for the presence of statistically significant ($\alpha \leq 0.05$) associations between the right side (negative) absolute nasal septum deviation and right side frontal cephalometric skeletal measurements using bivariate regression analysis. Interactions between genders were also analyzed. The bivariate regression analysis and gender interactions was repeated for left side (positive) absolute nasal septum deviation and left side frontal cephalometric skeletal measurements.

CHAPTER 3

RESULTS

Description of Population Demographics

Subjects and Enrollment

This study consisted of CBCT records of 23 males and 23 females (n=46) that were age matched. The average age of males was 25.43 years (minimum 15; maximum 50) and females was 26.04 years (minimum 16; maximum 50) (fig. 5).

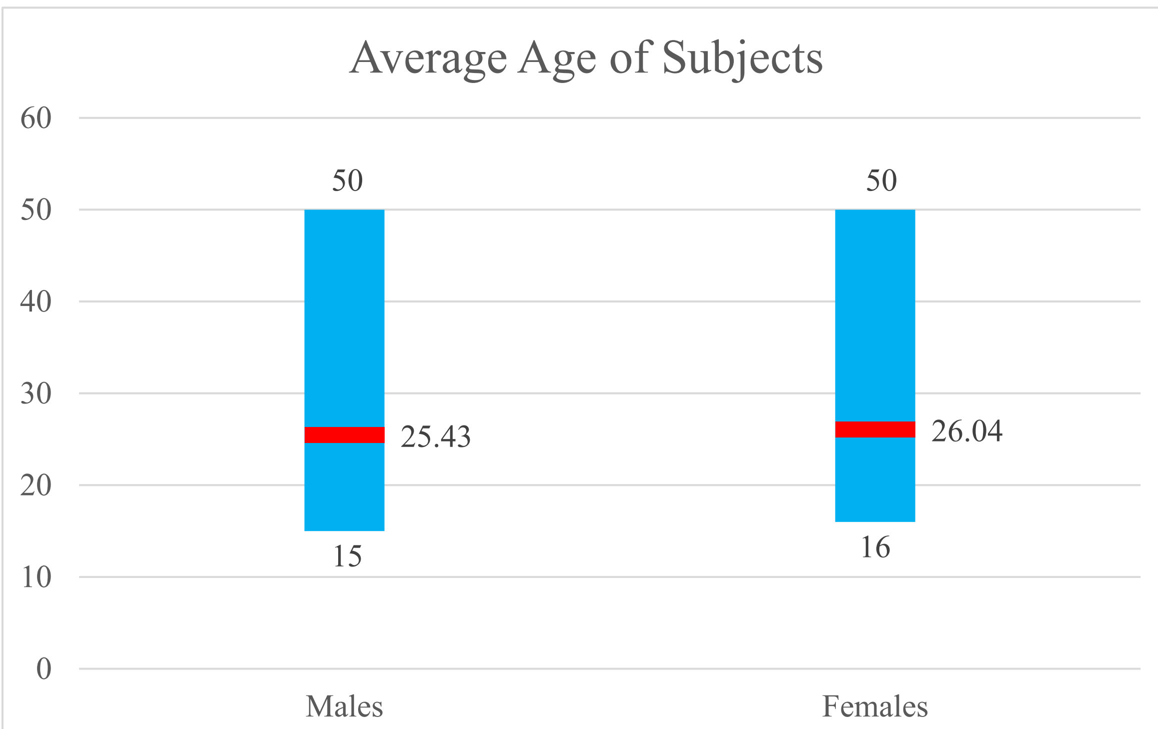

Figure 5. Distribution of Age of Subjects at time of CBCT scan. Minimum, average and maximum ages shown for each sex.

Skeletal Classification

This study consisted of CBCTs of 23 skeletal class I, 15 skeletal class II, and 8 skeletal class III subjects (fig. 6).

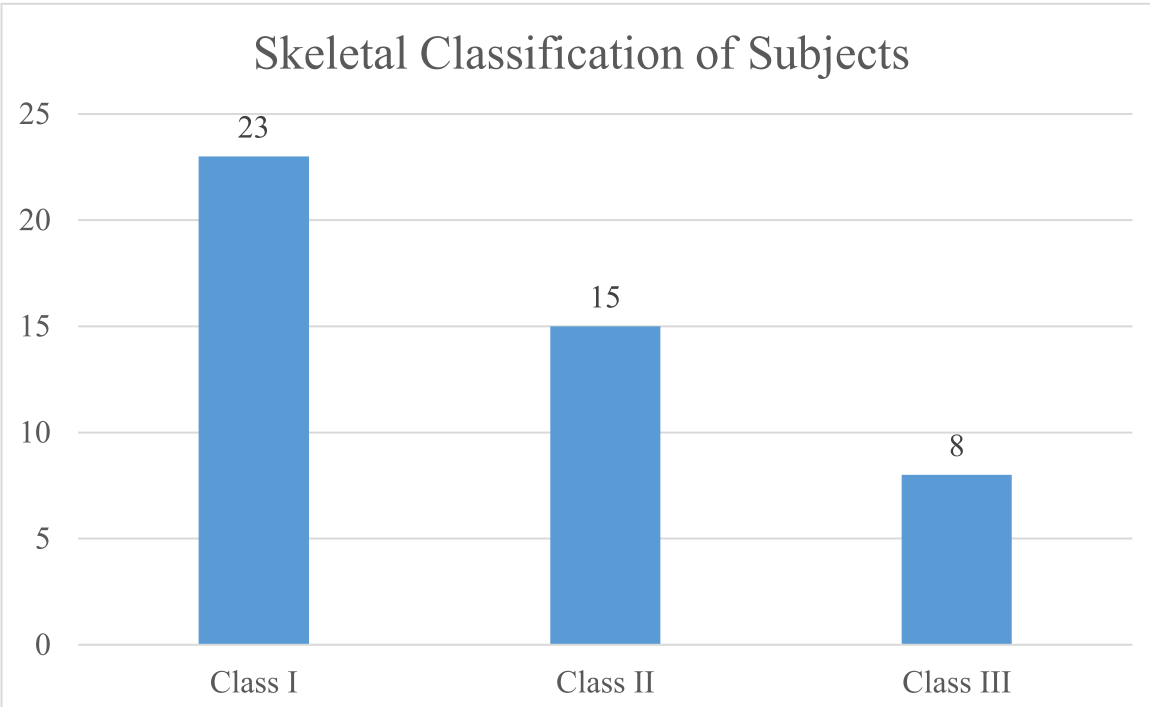

Figure 6. Distribution of subjects by skeletal classification.

Nasal Septum Cartilage

The average cartilaginous septal area of all subjects was 888.95 mm^2 (minimum 516.33 mm^2; maximum 1358.74 mm^2). The distribution across gender was similar for cartilaginous nasal septum area (fig. 7).

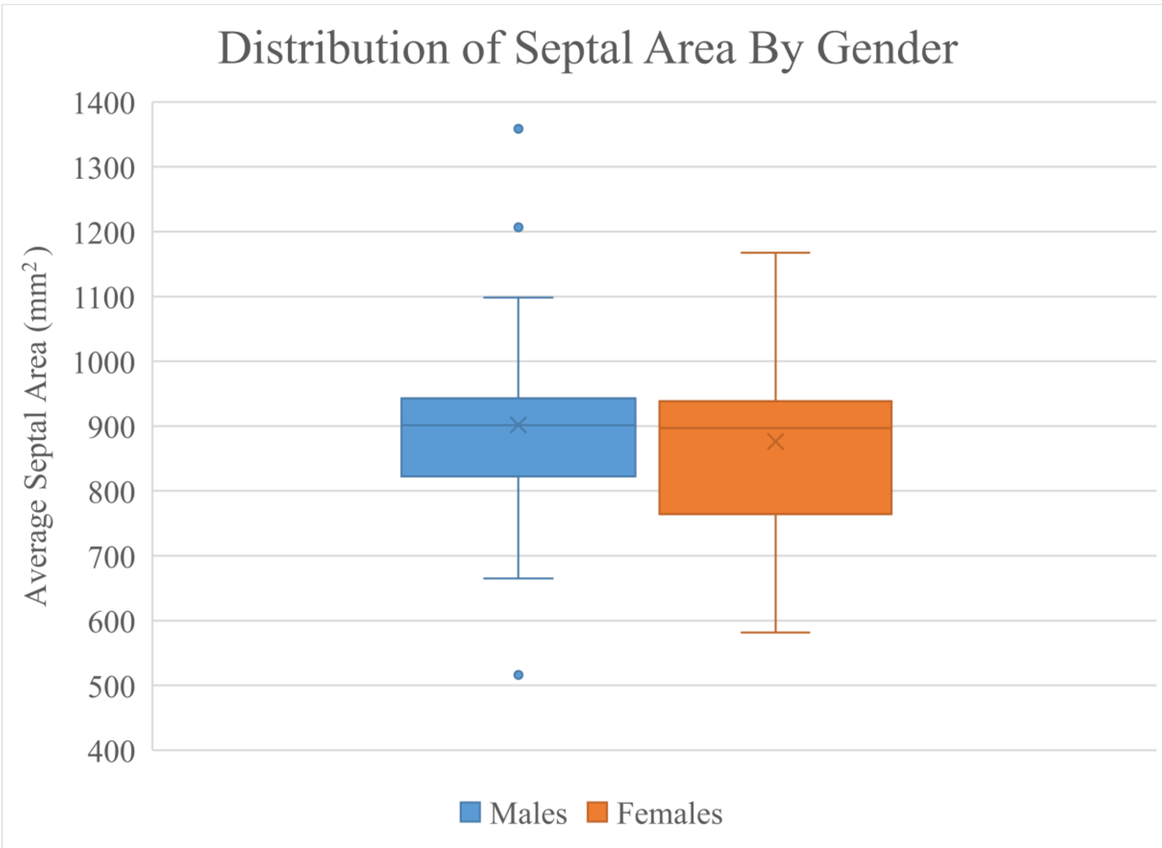

Figure 7. Distribution of cartilaginous septal area between males and females.

Nasal Septal Deviation

The average absolute septum deviation of all subjects was 10.06° (minimum 4.33°; maximum 18.5°). Of the 46 subjects, 28 subjects had deviations to the left side with an average of 10.36° (minimum 6.33°; maximum 18°) and 18 subjects had deviations to the right side with an average of 9.59° (minimum 4.33°; maximum 18.5°). The degree of nasal septum deviations was similar from right to left side (fig. 8). In males, the distribution of septal deviation was similar between left and right side deviations (fig. 9) but in females the distribution showed a larger deviation value to the left versus the amount of deviation to the right (fig. 10).

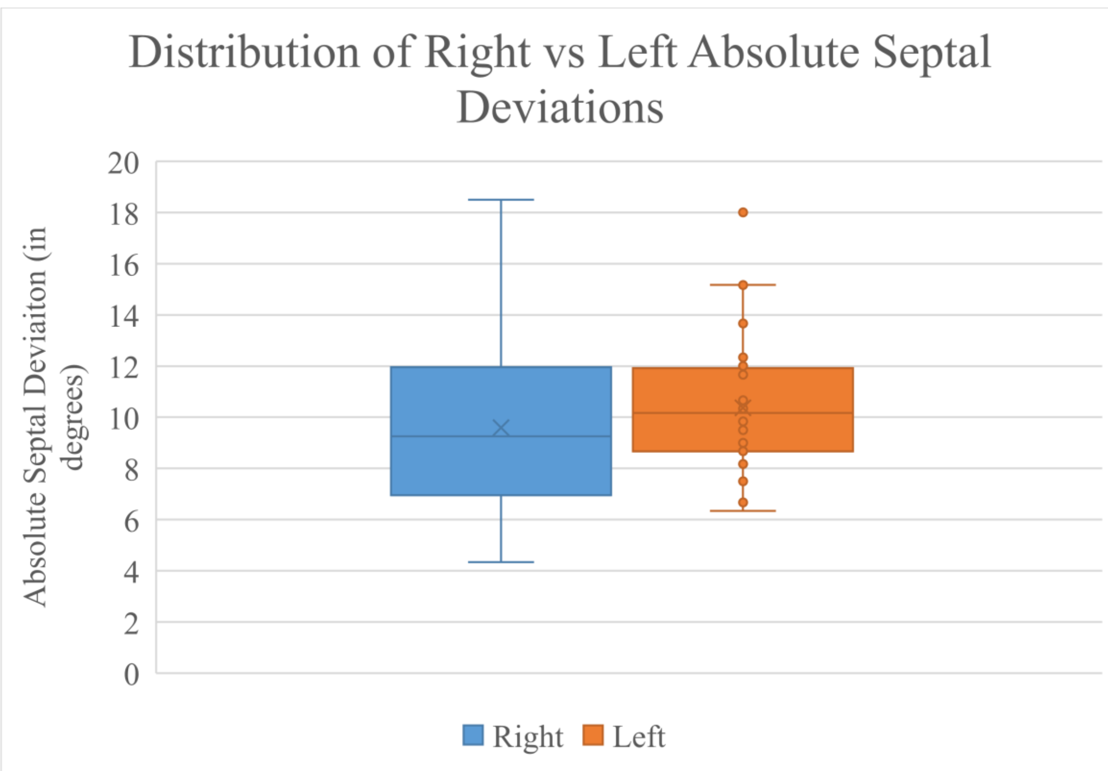

Figure 8. Distribution of ASD between right and left deviations.

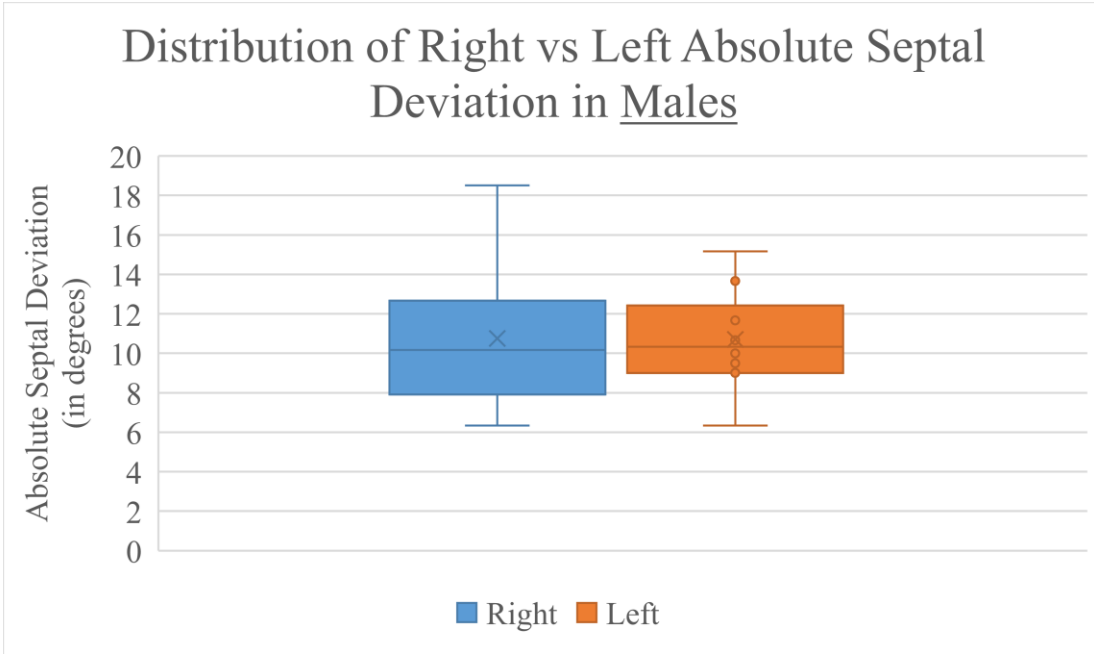

Figure 9. Distribution of ASD between right and left deviations in males.

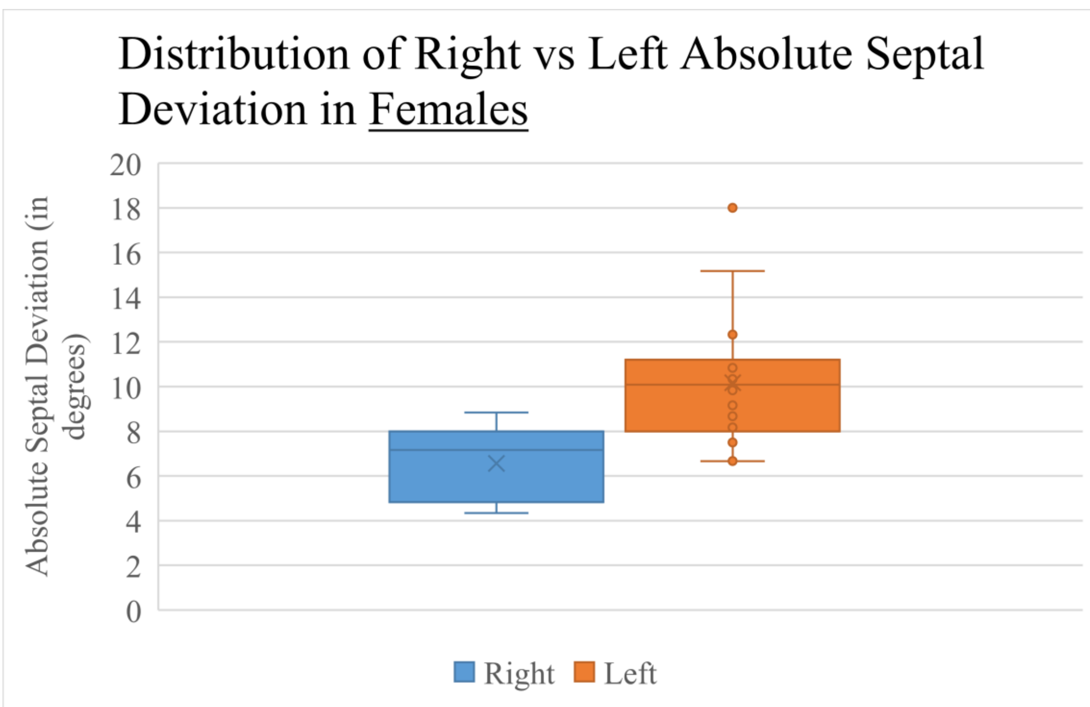

Figure 10. Distribution of ASD between right and left deviations in females.

Intra–rater Reliability Results

Cephalometric tracing consists of an observer selecting points on the cephalometric radiograph for each landmark. A single observer was used because there is greater inter–observer differences than intra–observer effects in cephalometric studies (Houston 1983; Trpkova et al. 1997; Kamoen et al. 2001). Before we collected the data, ten cases were randomly chosen to perform intra–rater reliability tests. All measurements that achieved an intraclass correlation coefficient (ICC) above 80% were included in the study. The majority of measurements had an ICC above 90% with five having ICCs between 80–90% (tables 4 and 5). We excluded U6–PP (mm) because the intra–rater reliability was below 80% (ICC = 53%).

TABLE 4

LATERAL CEPHALOMETRIC INTRA-RATER RELIABILITY

Region	**Measurements (angular and linear)**	**ICC**	**Minimum**	**Maximum**
Cranial Base	SN–FH (°)	0.90946161	4.1	17.2
	S–N (mm)	0.95196688	67.6	75.8
	S–Ba (mm)	0.91982133	40.1	54.2
	N–S–Ba (°)	0.87975329	122.3	135.7
	N–Ba/FH (°)	0.91643141	24.3	38.5
Maxillary Skeletal	SNA (°)	0.92717676	73.2	86.2
	Pt A to Na perp (mm) (N–A (// FH) (mm))	0.94648359	–4	9.1
	PP–FH (°)	0.86489668	–9.2	1.8
	Lande's angle (°) (FH/N–A)	0.94271426	85.4	99.6
	Co–Pt A (mm)	0.86822614	76.6	87.9
Mandibular Skeletal	SNB (°)	0.94276146	71	84.6
	Pog–Na perp (mm)	0.91121511	–6.6	16.9
	Facial angle (°)	0.90884977	86.2	99.2
	Go–Gn (mm)	0.92795557	68.1	84.9
	Co–Gn (mm)	0.96227474	105.1	121
	Ar–Go (mm)	0.93410343	37.9	52.9

Table 4 Continued

Region	Measurements (angular and linear)	ICC	Minimum	Maximum
Mandibular Skeletal	Ar–Go–Me (°)	0.93147345	119.7	139.6
	Ar–Go–N (°)	0.82531609	51.7	59.8
	N–Go–Me (°)	0.97649693	64.7	85.4
Maxillary / Mandibular	FMA (°)	0.94873515	14.7	30.2
	MP/SN (°)	0.97094397	21.6	46.8
	ANB (°)	0.96645618	–2.2	5.6
	Wits (mm)	0.97335069	–5.3	11.5
	Mx–md diff (mm)	0.96801833	23.3	35.1
	Molar relation (mm)	0.94752966	–3.6	4.2
Vertical	SN/S–Gn (°)	0.93743992	60.3	73.8
	N–Me (⊥FH) (mm)	0.96330823	105.6	125
	Nasion to ANS (mm)	0.91428765	45.8	57.9
	ANS to Me (mm)	0.97550251	56.1	68.4
	LAFH ratio (ANS–Me/N–Me)	0.9116051	51.1	57.1
	UFH/LAFH ratio	0.90580692	75.4	95.9
	S–Go (⊥FH) (mm)	0.96391648	67	86.4
	S–Go/N–Me (%)	0.96910518	56.6	74.9
Vertical Dentoalveolar	U1–ANS (mm)	0.94336116	21.1	30.6
	U6–PP (mm)	0.53045567	20	23
	L1–Me (mm)	0.9664531	34.7	42.8
Sagittal Dentoalveolar	U1–Pt A (V) (mm)	0.99551836	–2.7	8.3
	U1–SN (°)	0.98237885	84.5	113.6
	IMPA (°)	0.97168988	75.7	113.9
	FMIA (°)	0.97088187	48.5	82.4
	L1–A Pog (mm)	0.99359538	–6	5.8
	Interincisal angle (°)	0.99209531	117.1	162.1

TABLE 5

FRONTAL CEPHALOMETRIC INTRA-RATER RELIABILITY

Region	Measurements (angular and linear)	ICC	Minimum	Maximum
Transverse measurements (OVERALL, Right and Left from Midsagittal plane) (all mm unless noted)	Total Facial width (bizygomatic width)	0.997124	115.6	132.6
	Left Facial width	0.994892	54.6	68.7
	Right Facial width	0.996688	59.6	68.5
	Total Nasal width (bialare width)	0.927062	23.5	28.6
	Total Nasal width Manual	0.934664	23.5	28.5
	Left Nasal width	0.94796	9	15.5
	Right Nasal width	0.93608	12	17.5
	Total Maxillary width	0.964726	55.8	66.6
	Left Maxillary width	0.96878	26	34.4
	Right Maxillary width	0.961992	28	34.1
	Total Mandibular width (bigonial width)	0.988295	77.4	86.1
	Left Mandibular width (AG)	0.957784	36.6	45.2
	Right Mandibular width (GA)	0.967153	38.1	47.3
	Total Maxillary intermolar width (6–6)	0.937882	48.1	55.9
	Total Maxillary intermolar width Manual	0.955012	48	56
	Left Maxillary intermolar width (6–6)	0.9341	22.5	28.5
	Right Maxillary intermolar width (6–6)	0.904035	22.5	29.5
	Total Mandibular intermolar width (6–6)	0.924924	43.4	53.8
	Total Mandibular intermolar width Manual	0.918521	43.5	53.5
	Left Mandibular intermolar width (6–6)	0.85611	22.5	28
	Right Mandibular intermolar width (6–6)	0.902425	20	27.5
Vertical measurements (all mm unless noted)	Right ramus height	0.968531	47.6	63.4
	Left ramus height	0.947422	49.4	60.6
	Right OP	0.958447	65	74
	Left OP	0.936279	66	73
	Difference right–left OP	0.949016	–3.5	2
	OP cant (degree)	0.955549	–3.5	2.9

Cartilaginous Nasal Septum Area and Lateral Cephalometric Measurements

Of the 41 lateral cephalometric measurements collected (table 6) eight variables had a statistically significant association with septal area. For every 1mm^2 increase in cartilaginous nasal septal cartilage area:

1. Lower gonial angle increased by 0.011° ($p=0.02$)
2. Total anterior face height increased by 0.020mm ($p<0.01$)
3. Upper face height increased by 0.008mm ($p<0.01$)
4. Lower face height increased by 0.014mm ($p<0.01$)
5. Upper incisor vertical distance from ANS increased by 0.005mm ($p<0.01$)
6. Lower incisor vertical distance from menton increased by 0.007mm ($p=0.01$)
7. Anteroposterior position of upper incisors by 0.004mm ($p=0.03$)
8. Mandibular incisor angle decreased by 0.012° ($p=0.03$)

Interestingly, none of the linear and angular measurements describing the anteroposterior position of the maxilla were significantly associated with cartilaginous nasal septal area.

The relationship between cartilaginous septal area and many of the lateral cephalometric values were found to significantly differ by gender. Therefore, for subsequent analyses, we stratified the lateral cephalometric variables by gender.

TABLE 6

ASSOCIATIONS BETWEEN LATERAL CEPHALOMETRY MEASUREMENTS AND NASAL SEPTUM CARTILAGE AREA

Region	Measurements	Slope	95% CI		P–Value	Correlation with Nasal Septal Cartilage Area	Interaction with Gender p–value
			Lower	Upper			
Cranial Base	SN–FH (°)	–0.002	–0.006	0.003	0.53	–0.08	0.75
	S–N (mm)	0.003	–0.002	0.008	0.30	0.13	<0.01
	S–Ba (mm)	0.005	–0.002	0.012	0.14	0.22	<0.01
	N–S–Ba (°)	–0.003	–0.009	0.003	0.35	–0.10	0.43
	N–Ba/FH (°)	0.000	–0.003	0.004	0.81	0.03	0.08
Maxillary Skeletal	SNA (°)	–0.001	–0.006	0.005	0.73	–0.04	0.96
	Pt A to Na perp (mm)	–0.002	–0.007	0.003	0.45	–0.08	0.58
	PP–FH (°)	0.004	–0.001	0.009	0.09	0.20	0.19
	Lande's angle (°)	–0.002	–0.008	0.003	0.34	–0.11	0.55
	Co–Pt A (mm)	0.005	–0.003	0.014	0.21	0.19	<0.01
Mandibular Skeletal	SNB (°)	0.001	–0.007	0.010	0.74	0.05	0.89
	Pog–Na perp (mm)	–0.002	–0.019	0.016	0.84	–0.03	0.23
	Facial angle (°)	–0.002	–0.010	0.007	0.72	–0.06	0.24
	Go–Gn (mm)	0.008	–0.004	0.020	0.20	0.21	0.23
	Co–Gn (mm)	0.013	–0.003	0.029	0.11	0.26	<0.01
	Ar–Go (mm)	0.002	–0.010	0.014	0.71	0.06	0.04
	Ar–Go–Me (°)	0.013	–0.002	0.028	0.09	0.27	0.31
	Ar–Go–N (°)	0.002	–0.008	0.011	0.73	0.07	0.85
	N–Go–Me (°)	0.011	0.002	0.020	0.02	0.27	0.11
Maxillary / Mandibular	FMA (°)	0.011	–0.001	0.023	0.08	0.24	0.16
	MP/SN (°)	0.009	–0.004	0.023	0.16	0.20	0.43
	ANB (°)	–0.002	–0.007	0.002	0.28	–0.12	0.67
	Wits (mm)	–0.005	–0.012	0.001	0.11	–0.22	0.03
	Mx–md diff (mm)	0.008	–0.004	0.020	0.20	0.20	0.10
	Molar relation (mm)	0.000	–0.006	0.006	0.91	–0.02	0.39
Vertical	SN/S–Gn (°)	0.005	–0.002	0.012	0.18	0.17	0.31
	N–Me (⊥FH) (mm)	0.020	0.011	0.030	<0.01	0.40	<0.01
	Nasion to ANS (mm)	0.008	0.003	0.012	<0.01	0.39	<0.01

Table 6 Continued

Region	Measurements	Slope	95% CI		P–Value	Correlation with Nasal Septal Cartilage Area	Interaction with Gender p–value
			Lower	Upper			
Vertical	ANS to Me (mm)	0.014	0.007	0.021	<0.01	0.35	<0.01
	LAFH ratio	0.001	–0.002	0.004	0.54	0.07	0.32
	UFH/LAFH ratio	–0.004	–0.014	0.005	0.33	–0.10	0.38
	S–Go (⊥FH) (mm)	0.008	–0.008	0.025	0.31	0.18	0.01
	S–Go/N–Me (%)	–0.004	–0.016	0.007	0.48	–0.11	0.51
Vertical Dento-alveolar	U1–ANS (mm)	0.005	0.003	0.008	<0.01	0.31	<0.01
	L1–Me (mm)	0.007	0.002	0.012	0.01	0.29	0.01
Sagittal Dento-alveolar	U1–Pt A (V) (mm)	0.004	0.000	0.008	0.03	0.29	0.25
	U1–SN (°)	0.009	–0.010	0.028	0.35	0.17	0.53
	IMPA (°)	–0.012	–0.023	–0.001	0.03	–0.19	0.06
	FMIA (°)	0.001	–0.014	0.016	0.88	0.02	0.62
	L1–A Pog (mm)	0.002	–0.002	0.007	0.25	0.18	0.37
	Interincisal angle (°)	–0.006	–0.025	0.012	0.48	–0.09	0.92

As the cartilaginous nasal septal area was not associated with the variables describing the anteroposterior position of the maxilla, a step–wise multivariate regression model was created to find the predictive value of the cartilaginous nasal septal area combined with cranial base measurements on the effects of the sagittal relationship of the maxilla and mandible.

The first regression analysis was performed using only septal area as the predictor (table 7). Interestingly, the only significant outcome was the sagittal intermaxillary relationship (Wits) in females (R^2=12.50%, p=0.01).

TABLE 7

MODEL ASSOCIATION BETWEEN MAXILLO–MANDIBULAR OUTCOMES AND NASAL SEPTAL CARTILAGE AREA

Region	Outcome Measurement (Average)	Predictor	Slope	95% CI		P–Value	R^2	Model p–value
				Lower	Upper			
FEMALES								
Maxilla	SNA (°)	Septal Area	–0.002	–0.009	0.006	0.66	0.80%	0.66
	Pt A to Na perp (mm)		–0.007	–0.017	0.004	0.19	9.00%	0.19
	Lande's angle (°)		–0.007	–0.018	0.003	0.16	10.10%	0.16
	Co–Pt A (mm)		–0.002	–0.016	0.012	0.80	0.40%	0.80
Mandible	SNB (°)		0.000	–0.008	0.007	0.89	0.00%	0.89
	Pog–Na perp (mm)		–0.015	–0.033	0.002	0.08	9.30%	0.08
	Co–Gn (mm)		–0.001	–0.020	0.018	0.89	0.10%	0.89
Maxillo–Mandibular Relationship	ANB (°)		–0.001	–0.007	0.005	0.71	0.20%	0.71
	Wits (mm)		–0.008	–0.013	–0.002	0.01	12.50%	0.01
	Mx–md diff (mm)		0.000	–0.013	0.014	0.94	0.00%	0.94
MALES								
Maxilla	SNA (°)	Septal Area	–0.001	–0.009	0.007	0.85	0.10%	0.85
	Pt A to Na perp (mm)		0	–0.007	0.007	0.93	0.00%	0.93
	Lande's angle (°)		0	–0.007	0.006	0.96	0.00%	0.96
	Co–Pt A (mm)		0.008	–0.002	0.018	0.11	10.30%	0.11
Mandible	SNB (°)		0.002	–0.011	0.016	0.74	0.50%	0.74
	Pog–Na perp (mm)		0.004	–0.022	0.030	0.75	0.50%	0.75
	Co–Gn (mm)		0.018	–0.006	0.042	0.13	14.30%	0.13
Maxillo–Mandibular Relationship	ANB (°)		–0.003	–0.009	0.003	0.35	2.40%	0.35
	Wits (mm)		–0.004	–0.014	0.006	0.41	2.60%	0.41
	Mx–md diff (mm)		0.01	–0.009	0.029	0.29	7.20%	0.29

The second regression analysis was performed using septal area, anterior cranial base (S–N in mm), posterior cranial base (S–Ba in mm), and cranial base angle (N–S–Ba in degrees) as the predictor variables.

In females, the model association was significant ($p<0.05$) with the following outcome variables (table 8):

1) Anteroposterior position of the maxilla relative to cranial base (SNA) (R^2=23.80%, p=0.02), 2)
2) Total maxillary length (Co–Pt A) (R^2=60.80%, p<0.01)
3) Sagittal intermaxillary relationship (Wits) (R^2=14.20%, p=0.03)

TABLE 8

MODEL ASSOCIATION BETWEEN MAXILLO–MANDIBULAR OUTCOMES AND NASAL SEPTAL CARTILAGE AREA, ANTERIOR CRANIAL BASE, POSTERIOR CRANIAL BASE, AND CRANIAL BASE ANGLE IN FEMALES

Region	**Outcome Measurement (Average)**	**Predictor**	**Slope**	**95% CI**		**P–Value**	**R^2**	**Model p–value**
				Lower	**Upper**			
Maxilla	SNA (°)	Septal Area	–0.003	–0.009	0.004	0.41		
		S–N	0.177	–0.249	0.603	0.40		
		S–Ba	0.367	0.102	0.631	0.01		
		N–S–Ba	–0.059	–0.326	0.207	0.65	23.80%	0.02
	Pt A to Na perp (mm)	Septal Area	–0.006	–0.018	0.006	0.28		
		S–N	0.05	–0.349	0.449	0.80		
		S–Ba	0.129	–0.405	0.663	0.62		
		N–S–Ba	0.124	–0.24	0.489	0.48	12.50%	0.73
	Lande's angle (°)	Septal Area	–0.007	–0.018	0.005	0.25		
		S–N	0.022	–0.381	0.425	0.91		
		S–Ba	0.109	–0.425	0.643	0.67		
		N–S–Ba	0.13	–0.236	0.496	0.47	13.40%	0.67
	Co–Pt A (mm)	Septal Area	–0.002	–0.012	0.009	0.76		
		S–N	0.955	0.62	1.289	<0.01		
		S–Ba	0.72	0.333	1.107	<0.01		
		N–S–Ba	0.261	–0.025	0.546	0.07	60.80%	<0.01

Table 8 Continued

Region	Outcome Measurement (Average)	Predictor	Slope	95% CI		P–Value	R^2	Model p–value
				Lower	Upper			
Mandible	SNB (°)	Septal Area	–0.002	–0.008	0.005	0.54	14.90%	0.05
		S–N	0.25	–0.208	0.707	0.27		
		S–Ba	0.169	–0.027	0.365	0.09		
		N–S–Ba	–0.193	–0.434	0.047	0.11		
	Pog–Na perp (mm)	Septal Area	–0.015	–0.034	0.004	0.11	10.60%	0.53
		S–N	0.281	–0.48	1.042	0.45		
		S–Ba	–0.067	–0.988	0.854	0.88		
		N–S–Ba	0.036	–0.682	0.753	0.92		
	Co–Gn (mm)	Septal Area	–0.002	–0.02	0.017	0.86	13.90%	0.17
		S–N	0.585	–0.138	1.309	0.11		
		S–Ba	0.535	0.012	1.058	0.05		
		N–S–Ba	0.116	–0.314	0.546	0.58		
Maxillo–Mandibular Relationship	ANB (°)	Septal Area	–0.001	–0.007	0.005	0.82	7.10%	0.32
		S–N	–0.071	–0.438	0.296	0.69		
		S–Ba	0.195	–0.051	0.441	0.11		
		N–S–Ba	0.135	–0.144	0.415	0.32		
	Wits (mm)	Septal Area	–0.008	–0.014	–0.001	0.02	14.20%	0.03
		S–N	–0.079	–0.589	0.432	0.75		
		S–Ba	0.106	–0.248	0.461	0.54		
		N–S–Ba	0.025	–0.319	0.369	0.88		
	Mx–md diff (mm)	Septal Area	0	–0.015	0.015	0.99	5.10%	0.75
		S–N	–0.369	–1.124	0.386	0.32		
		S–Ba	–0.187	–0.75	0.377	0.50		
		N–S–Ba	–0.144	–0.629	0.341	0.54		
		S–N	–0.273	–1.01	0.463	0.45		
		S–Ba	–0.189	–1.177	0.799	0.69		
		N–S–Ba	0.226	–0.392	0.844	0.45		
	Mx–md diff (mm)	Septal Area	0.008	–0.012	0.028	0.40	23.90%	0.09
		S–N	0.066	–0.53	0.662	0.82		
		S–Ba	0.264	–0.565	1.092	0.51		
		N–S–Ba	–0.477	–1.095	0.141	0.12		

In males, the model association was significant ($p<0.05$) with the outcomes (table 9):

1) Total maxillary length (Co–Pt A) (R^2=35.20%, p=0.04)

2) Anteroposterior position of mandible from nasion (SNB) (R^2=31.40%, p=0.02)

3) Sagittal intermaxillary relationship (ANB) (R^2=40.00%, p=0.03)

TABLE 9

MODEL ASSOCIATION BETWEEN MAXILLO–MANDIBULAR OUTCOMES AND NASAL SEPTAL CARTILAGE AREA, ANTERIOR CRANIAL BASE, POSTERIOR CRANIAL BASE, AND CRANIAL BASE ANGLE IN MALES

Region	Outcome Measurement (Average)	Predictor	Slope	95% CI		P–Value	R^2	Model p–value
				Lower	Upper			
Maxilla	SNA (°)	Septal Area	–0.001	–0.009	0.008	0.89		
		S–N	–0.798	–1.649	0.054	0.07		
		S–Ba	0.387	–0.245	1.018	0.22		
		N–S–Ba	–0.073	–0.438	0.292	0.68	37.20%	0.09
	Pt A to Na perp (mm)	Septal Area	0.002	–0.007	0.011	0.63		
		S–N	–0.79	–1.866	0.285	0.14		
		S–Ba	0.159	–0.454	0.773	0.59		
		N–S–Ba	0.412	–0.033	0.857	0.07	24.00%	0.28
	Lande's angle (°)	Septal Area	0.002	–0.007	0.01	0.71		
		S–N	–0.722	–1.751	0.308	0.16		
		S–Ba	0.12	–0.475	0.716	0.68		
		N–S–Ba	0.365	–0.065	0.794	0.09	22.20%	0.34
	Co–Pt A (mm)	Septal Area	0.006	–0.004	0.017	0.20		
		S–N	–0.196	–1.088	0.697	0.65		
		S–Ba	0.464	–0.205	1.133	0.16		
		N–S–Ba	0.526	0.13	0.923	0.01	35.20%	0.04
Mandible	SNB (°)	Septal Area	–0.001	–0.014	0.013	0.90		
		S–N	–0.233	–1.128	0.663	0.59		
		S–Ba	0.651	–0.326	1.628	0.18		
		N–S–Ba	–0.285	–0.8	0.229	0.26	31.40%	0.02
	Pog–Na perp (mm)	Septal Area	0.001	–0.03	0.032	0.96		
		S–N	–0.077	–1.876	1.721	0.93		
		S–Ba	0.681	–1.032	2.393	0.42		
		N–S–Ba	0.133	–0.948	1.214	0.80	4.00%	0.83
	Co–Gn (mm)	Septal Area	0.015	–0.011	0.04	0.25		
		S–N	–0.129	–1.191	0.934	0.80		
		S–Ba	0.727	–0.416	1.871	0.20		
		N–S–Ba	0.049	–0.764	0.862	0.90	20.10%	0.26

Table 9 Continued

Region	Outcome Measurement (Average)	Predictor	Slope	95% CI		P–Value	R^2	Model p–value
				Lower	Upper			
Maxillo–Mandibular Relationship	ANB (°)	Septal Area	0	–0.007	0.008	0.94		
		S–N	–0.568	–1.14	0.005	0.05		
		S–Ba	–0.264	–0.893	0.364	0.39		
		N–S–Ba	0.213	–0.182	0.608	0.27	40.00%	0.03
	Wits (mm)	Septal Area	–0.002	–0.014	0.01	0.73		
		S–N	–0.273	–1.01	0.463	0.45		
		S–Ba	–0.189	–1.177	0.799	0.69		
		N–S–Ba	0.226	–0.392	0.844	0.45	13.80%	0.32
	Mx–md diff (mm)	Septal Area	0.008	–0.012	0.028	0.40		
		S–N	0.066	–0.53	0.662	0.82		
		S–Ba	0.264	–0.565	1.092	0.51		
		N–S–Ba	–0.477	–1.095	0.141	0.12	23.90%	0.09

Absolute Septal Deviation and Frontal Cephalometric Measurements

The absolute septal deviations were divided in two groups for analysis. The first group consisted of deviations with a negative angular ASD measurement indicating a deviation to the right side. The second group consisted of deviations with a positive angular ASD measurement indicating a deviation to the left side.

Right side absolute septal deviations had statistically significant correlations with (table 10):

1. Right facial width (p<0.01)
2. Right mandibular width (p=0.04)
3. Right occlusal plane (p=0.02)

TABLE 10

ASSOCATIONS BETWEEN RIGHT FRONTAL CEPHALOMETRIC MEASUREMENTS AND RIGHT ABSOLUTE SEPTAL DEVIATION (ASD)

Measurements (N=18)	**Slope**	**95% CI**		**p–value**	**Correlation with ASD**	**Interaction with Gender p–value**
		Lower	**Upper**			
Right Facial width	–0.340	–0.550	–0.130	<0.01	–0.33	0.01
Right Nasal width	–0.020	–0.140	0.110	0.79	–0.04	0.83
Right Maxillary width	–0.170	–0.390	0.060	0.14	–0.33	0.32
Right Mandibular width (GA)	–0.470	–0.930	–0.020	0.04	–0.47	0.10
Right Maxillary intermolar width (6–6)	0.000	–0.320	0.320	0.99	0.00	0.22
Right Mandibular intermolar width (6–6)	–0.190	–0.520	0.150	0.26	–0.27	0.12
Right ramus height	–0.210	–0.870	0.440	0.50	–0.13	0.30
Right OP	–0.500	–0.910	–0.090	0.02	–0.42	0.03

No measurements were significantly associated with left side absolute septal deviations and left side measurements (table 11).

TABLE 11

ASSOCATIONS BETWEEN LEFT FRONTAL CEPHALOMETRIC MEASUREMENTS AND LEFT ABSOLUTE SEPTAL DEVIATION (ASD)

Measurements (N=28)	**Slope**	**95% CI**		**p–value**	**Correlation with ASD**	**Interaction with Gender p–value**
		Lower	**Upper**			
Left Facial width	–0.090	–0.600	0.420	0.71	–0.08	<0.01
Left Nasal width	0.060	–0.100	0.210	0.45	0.17	0.07
Left Maxillary width	–0.050	–0.360	0.260	0.75	–0.06	0.02
Left Mandibular width (GA)	–0.140	–0.600	0.310	0.52	–0.15	0.56
Left Maxillary intermolar width (6–6)	–0.100	–0.340	0.150	0.43	–0.16	0.19
Left Mandibular intermolar width (6–6)	–0.140	–0.410	0.130	0.31	–0.24	0.37
Left ramus height	0.030	–0.340	0.410	0.85	0.03	0.01
Left OP	0.260	–0.160	0.690	0.21	0.19	<0.01

There was a significant gender interaction between right side deviations with right facial width and right occlusal plane. There was also a significant gender interaction between left side deviations with left facial width, left maxillary width, left ramus height and left occlusal plane. The regression analysis was repeated for these measurements stratifying by gender (tables 12 and 13). None of the right side measurements were significantly associated within either gender. For the left side measurements there was a statistically significant association between left nasal septum deviation and left side ramus height in males (p=0.02).

TABLE 12

ASSOCIATION BETWEEN RIGHT FRONTAL CEPHALOMETRIC MEASUREMENTS AND RIGHT ABSOLUTE SEPTAL DEVIATION (ASD) BY GENDER

Measurements	Slope	95% CI		P–Value
		Lower	Upper	
FEMALES				
Right Facial width	–0.323	–0.972	0.325	0.21
Right OP	0.693	–1.49	2.876	0.39
MALES				
Right Facial width	–0.176	–0.42	0.069	0.14
Right OP	–0.403	–0.989	0.182	0.16

TABLE 13

ASSOCIATION BETWEEN LEFT FRONTAL CEPHALOMETRIC MEASUREMENTS AND LEFT ABSOLUTE SEPTAL DEVIATION (ASD) BY GENDER

Measurements	Slope	95% CI		P–Value
		Lower	Upper	
FEMALES				
Left Facial width	–0.194	–0.669	0.281	0.40
Left Maxillary width	0.121	–0.146	0.387	0.35
Left ramus height	–0.31	–0.654	0.035	0.08
Left OP	–0.04	–0.347	0.266	0.78
MALES				
Left Facial width	–0.076	–0.894	0.742	0.84
Left Maxillary width	–0.602	–1.25	0.045	0.06
Left ramus height	0.786	0.152	1.421	0.02
Left OP	0.805	–0.122	1.731	0.08

CHAPTER 4

DISCUSSION

In human development, the postnatal craniofacial growth remains to be poorly understood. The successful growth of the entire craniofacial complex occurs surprisingly well with so many different processes taking place concurrently. It is well known that during postnatal growth of maxilla, there is bony apposition around the circum-maxillary sutures, as well as a downward (inferior) and forward (anterior) displacement (Enlow and Hans 2008b). In addition to this displacement, the maxilla as also undergoes surface remodeling (resorption and deposition of bone). Oftentimes patients present with a varying degree of maxillary hypoplasia or hyperplasia, with or without maxillary retrusion or maxillary prognathism, possibly resulting in a skeletal malocclusion. Over the years, many different theories of craniofacial growth have been proposed, including the nasal septum hypothesis, which was a major focus of this research (Scott 1953; Pritchard et al. 1956). Based on this hypothesis, the nasal septum cartilage plays a critical role in midface development by influencing the downward and forward growth of the midface. While previous studies have assessed the septal cartilage growth in vitro (Copray 1986; Al Dayeh and Herring 2014) and in animal models (Sarnat and Wexler 1966; Sarnat and Wexler 1967) and others have examined the relative septal deviations and asymmetries (Hartman et al. 2016), to date there has been no study performed that assessed the nasal septal cartilage area and anteroposterior position of maxilla along with absolute septal deviation and facial asymmetries. We hypothesized that if the nasal septum cartilage was truly acting as a growth center, an increase in cartilage size would create a larger force, or push effect, on the maxilla and increase the downward and forward displacement of the maxilla in the sagittal dimension. Therefore, we anticipated an association correlation between the nasal septal cartilage area and anteroposterior position of the maxilla. We also hypothesized that if the nasal septum cartilage possessed the properties of a growth center, that if deviated during growth it would cause an asymmetry of the facial skeleton in the frontal view, which will be reflected as an association between degree of septal deviation and bilateral width.

Nasal Septal Cartilage Area and Maxillary Anteroposterior Association

When assessing for an association between nasal septal cartilage area and lateral cephalometric measurements for maxilla, we found no statistically significant association between the two, thereby failing to reject the null hypothesis of this study. Interestingly, we did find a statistically significant correlation between nasal septal cartilage area with the lower gonial angle, total facial height, upper facial height, and lower facial height. All of these variables describe the facial skeleton in the vertical dimension. This data would suggest that growth of the nasal septum cartilage could exert more of a downward vector than a forward vector on the direction of the growth of the maxilla. This could increase the upper facial height, with a resultant increase in lower facial height and total facial height. Therefore, in the net downward and forward displacement of the maxilla, cartilaginous nasal septum area appears to influence the facial skeleton in downward (vertical dimension) rather than the forward direction (anteroposterior dimension).

Nasal Septum Deviation and Frontal Asymmetries

The second hypothesis was to assess if the absolute septal deviation was associated with frontal cephalometric asymmetries. There were significant correlations between right side absolute septal deviations and right side facial measurements. These included right facial width, right mandibular width, and right occlusal plane. Interestingly all of these values had a negative slope indicating that as the septum increased in deviation by 1 degree to the right the right facial width decreased by 0.34mm, the right mandibular width decreased by 0.47mm and the right occlusal plane decreased by 0.50mm. Left side deviations and left side facial measurements had no significant correlations possibly due to the nature of the dataset or inadequate power to detect significant differences. There were multiple measurements with a significant gender interaction in both right and left deviations with right and left facial measurements, respectively. Of the measurements with a significant gender interaction only left side deviations and left ramus height in males was significant with a positive slope indicating that as the left nasal septum deviation increased by 1 degree, the left ramus height increased by 0.786mm. This may corroborate with findings of previous reports that patients with extreme craniofacial disorders, such as hemifacial microsomia, the skeletal asymmetries tend to be present more often with the right side of the face (Haraguchi et al. 2008; Cassi et al. 2017).

Facial Growth Model Predictor

A model was created to evaluate the combined effects of septal cartilage area and cranial base measurements on the anteroposterior position of maxilla as well as the mandible. Our study's sample population showed very little difference in nasal septal cartilage area size between males and females, yet we see some very different effects in the results between males and females. This can be explained from the sexual dimorphisms present at the end of adolescence. Of special interest is that our model predictors found a significance in both males and females for the outcome variable – total maxillary length (Co–Pt A). When looking at the model for each gender specifically, some stark differences arise. In females the outcome is mainly influenced by the anterior and posterior cranial base lengths, yet in males it is mainly influenced by the addition of the cranial base angle. In males, the anterior cranial base length actually has a negative effect due to the negative slope. Previous studies have been shown that in males, on average, growth of the mandible continues past that of females with males exhibiting counterclockwise rotation of the mandible and females exhibiting a clockwise rotation of the mandible (Behrents 2008). This results in males having an increased SNB and thus decreased ANB which is seen in our model association outcomes.

Implications to Growth and Development

Based on all the available information known about growth of the nasomaxillary complex, we hypothesized that the nasal septum cartilage area would correlate well with the anteroposterior position of the maxilla. However, we have failed to reject the null hypothesis of this study as no significant associations were detected between the septal area and the linear/angular measurements of the maxilla. Even the inclusion of the cranial base measurements in our model predictor only accounted for the anteroposterior maxillary position by 60.80% in females and 35.20% in males. Clearly there are other factors at play and our study did not capture these factors. The results of this study indicate the complexity of craniofacial growth. The postnatal growth of the nasomaxillary complex is influenced by the cranial base growth and the apposition of bone at the circum-maxillary sutures along with surface remodeling. Our results indicate that growth of the nasal septal cartilage seems to contribute minimally to the forward growth vector of the maxilla. If there is any effect, it is mostly in downward direction in our study population. It is possible that the growth at the circum-maxillary sutures, and surface remodeling, may be masking the effect of the nasal septal cartilage, which cannot be evaluated in the current study. It is also possible that Scott's theory is overstated and there is no direct relationship between the growth of the nasal septal cartilage and nasomaxillary complex. Regardless, an important highlight of this study were the differences noted in males and females. It is known from the work of Behrent et al with the Bolton Growth Study (2008) that males and females have differences in growth patterns in adulthood. Our study highlights that there is indeed a difference between males and females with regards to septal area association with craniofacial variables. As this study was performed at one time point on a cohort of subjects at different ages, the results of the study need to be interpreted with caution. In summary, the size of the nasal septum cartilage may be affecting vertical growth of the midface and absolute septal deviation may affect the symmetry of the facial skeleton, however future studies in larger sample are needed.

Clinical Implications

Based on our study data, changes in nasal septal cartilage area values could potentially have drastic effects on craniofacial skeletal morphology, particularly in the vertical dimension. This study had a range of nasal septum area measurements from minimum 516.33mm^2 to maximum 1358.74mm^2 for a total range of 842.41mm^2. While the slopes associated with the significantly significant associations of lower gonial angle (slope=0.011), upper face height (slope=0.008), lower face height (slope=0.014), and total face height (slope=0.020), the large range of nasal septum cartilage areas could create effects that become clinically relevant. For example, an increase from the smallest nasal septum area of 516.33mm^2 to the average male nasal septum cartilage area of 901.82mm^2 is an increase of 385.49mm^2. Based on the slope for upper face height of 0.008 this would translate to a 3.08mm increase in the upper face height which would be clinically relevant. We must remain aware that the alteration of one craniofacial unit will have a cascading effect on the remainder of the craniofacial unit and that is unpredictable at this time with this data. While we are unable to alter or control the size of nasal septum cartilage in humans during growth, this could become a diagnostic tool to determine the vertical facial type if normalized age matched data was captured in the future.

Study Limitations

Our study did have some limitations present that could have influenced the results. The CBCT data is a very reliable tool to test our hypotheses as the measurements have been shown to be in a true 1:1 ratio (Ludlow et al. 2007; Kamburoglu et al. 2011). This eliminates the differential magnification of superimposed bilateral structures, which would be a problem in traditional cephalometric radiographs. While there are benefits in using CBCT, not all of our scans were made from the same machine. Therefore the inherent errors arising from the scans made in different machines cannot be eliminated. Additionally, CBCT is not ideal imaging to capture soft tissue such as the cartilage of the nasal septum. We overcame this limitation by using the bony boundaries to identify the nasal septum cartilage, but ideally an MRI would be taken to measure the nasal septum cartilage area and the CBCT would be taken for bony structure identification and measurement. Another major limitation of this study was the inclusion of multiple different age groups at one time point. This was necessary in this study to collect as many CBCTs as possible to attempt to ascertain a statistical power to identify associations. Our study was limited by the convenience sample size of 46 subjects.

Future Investigations

Future studies need to be replicated on a larger sample size. Ideally a power analysis prior to data collection to determine the sample size should be performed. It would be ideal to have a longitudinal approach to this type of study with different age groups using the same

CBCT machine. As CBCT radiation exposure level decreases with each new generation of machines, it may be possible in the future to develop a legacy collection of CBCTs of the same individuals at different ages to assess craniofacial growth in three dimensions. The CBCT technology will also reduce any magnification changes from one time point to another from growth of the craniofacial unit causing a change in head position relative to the film in traditional longitudinal cephalometric studies.

CBCT machines are also able to calculate airway volume/size. Since researchers and clinicians alike are starting to understand the possible importance of the type of breathing (nasal vs mouth breathing) on craniofacial growth, with the nasal septum being a major contributor to the upper airway and pharyngeal muscles being the major contributor to the middle airway, it would be interesting to combine these factors to see the influence on the development of craniofacial structures.

Lastly, future studies should include upper and lower posterior face heights in the data collection to assess the changes to the posterior face height. While the palatal plane angle was not statistically significant ($p=0.09$), it did have a positive correlation with nasal septal cartilage area. It would be ideal to evaluate if the increase in upper anterior face height seen in CBCTs with larger nasal septum areas also have an increase in upper posterior face height. This would help determine if there is a clockwise rotation of the maxilla resulting in an increased palatal plane angle or the maxilla as an entire unit is moving in a downward direction.

CHAPTER 5

CONCLUSIONS

1. There was no significant association ($p>0.05$) between nasal septum cartilage area and maxillary anteroposterior position.
2. There was significant association ($p<0.05$) between right absolute septal deviation and right facial width, right mandibular width, and right OP.

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APPENDIX A

IRB LETTER

UMKC
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UMKC
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NOT HUMAN SUBJECTS RESEARCH DETERMINATION

Principal Investigator: Dr. Shankar Rengasamy Venugopalan
650 East 25th Street
Kansas City, MO 64108

Protocol Number: 17-115
Protocol Title: ASSOCIATION BETWEEN NASAL SEPTUM SIZE/ DEVIATION AND SAGITTAL MAXILLARY POSITION AND SKELETAL ASYMMETRY
Type of Review: Not Human Subjects Determination

Date of Determination: 04/19/2017

Dear Dr. Rengasamy Venugopalan,

The above referenced study, and your participation as a principal investigator, was reviewed and determined to be Not Human Subjects Research (NHSR). As such, your activity falls outside the parameters of IRB review. You may conduct your study, without additional obligation to the IRB, as described in your application.

The NHSR Determination is based upon the following Federally provided definitions:

"Research" is defined by these regulations as "a systematic investigation, including research development, testing and evaluation, designed to develop or contribute to generalizable knowledge."

The regulations define a **"Human Subject"** as "a living individual about whom an investigator (whether professional or student) conducting research obtains: data through intervention or interaction with the individual, or identifiable private information."

Attachments include the following:
Attachments

All Human Subjects Research must be submitted to the IRB. If your study changes in such a way that it becomes Human Subjects Research, please contact the Research Compliance office immediately for the appropriate course of action.

Please contact the Research Compliance Office (email: umkcirb@umkc.edu; phone: (816)235-5927) if you have questions or require further information.

Thank you,

Crystal Simonis
UMKC IRB Administrative Office

VITA

NAME:

Kevin Charles Kaiser

DATE AND PLACE OF BIRTH:

April 6, 1990; St. Louis, Missouri

EDUCATION:

2008	Diploma	Lindbergh High School St. Louis, Missouri
2012	BS/Biology	University of Missouri Columbia, Missouri
2016	DDS	University of Missouri-Kansas City School of Dentistry Kansas City, Missouri

PROFESSIONAL ORGANIZATIONS:

2016-present	American Association of Orthodontists, Member
2016-present	American Dental Association, Member
2012-2016	Student Professionalism and Ethics Association, Chief Information officer, National level
2012-2016	Xi Psi Phi, Member
2012-2016	American Students Dental Association, Member

SELECTED HONORS:

2016	Omicron Kappa Upsilon National Dental Honor Society
2015	ADA Student Ethics Contest Grand Prize Winner
2005	Eagle Scout