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Cone-Beam Computed Tomography Analysis of Facial Asymmetry: Relating Septal Deviations and Uneven Nasal Breathing with Asymmetric Facial Growth

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Cone-Beam Computed Tomography Analysis of Facial Asymmetry:

Relating Septal Deviations and Uneven Nasal Breathing with Asymmetric Facial Growth

A thesis submitted in partial satisfaction of the requirements for

the degree Master of Science in Oral Biology

by

Alison Marie Lemkuil

2024

ABSTRACT OF THE THESIS

Cone-Beam Computed Tomography Analysis of Facial Asymmetry:

Relating Septal Deviations and Uneven Nasal Breathing with Asymmetric Facial Growth

by

Alison Marie Lemkuil

Master of Science in Oral Biology

University of California, Los Angeles, 2024

Professor Sanjay M. Mallya, Chair

Facial asymmetry can be defined as a mismatch in the shape, location, and size of facial structures bilaterally. While mild asymmetry in human anatomy is considered normal, there are a multitude of factors that can contribute to significant deviations from normal. Understanding the etiologies of facial asymmetry is essential for diagnosing and treating symptoms related to these deviations. Two important areas to consider when assessing facial asymmetry include nasal septum deviations and the internal nasal valve.

The long-term goal of this project was to utilize 3-Dimensional analysis of initial CBCT radiographs of orthodontic patients to relate nasal septal deviations and uneven nasal airway, as represented by the internal nasal valve (INV), with asymmetric facial growth. Clinical applications and significance of these findings include analyzing how orthodontic appliances and otolaryngology treatments may contribute to improvement of oral and nasal airways, incorporating internal nasal valve angle and cross-sectional area in nasal airway analysis on

CBCT, and ultimately helping patients breathe better and grow symmetrically through an enhanced understanding of the etiologies of nasal and facial asymmetry. We hypothesized that asymmetric nasal airway would affect facial asymmetry and that patients with nasal septum deviation would have significant facial asymmetry related to this deviation. Our specific aims included quantifying the internal nasal valve angle and cross-sectional area using CBCT, identifying degrees of nasal septal deviations, and analyzing facial asymmetry using 3-dimensional CBCT data to relate extraoral asymmetry with nasal asymmetry.

This study was a retrospective study evaluating the initial CBCT scans for 25 patients at the UCLA Orthodontics Clinic who were diagnosed with a deviated nasal septum on the UCLA Radiology Report prior to beginning treatment. CBCT files were analyzed using Dolphin Imaging software, and statistical analysis via bivariate correlation was performed to assess significant relationships between nasal and facial asymmetry. Our results demonstrated a significant negative correlation between nasal septum deviation and the internal nasal valve, suggesting that as the angle of septum deviation increased, the internal nasal valve angle and cross-sectional area decreased. However, this study did not necessarily demonstrate the anticipated relationship between nasal and facial asymmetry as seen in other studies. We found a significant correlation between the absolute value of the angle of septum deviation and absolute value of chin deviation at menton. There was also a positive correlation between the angle of the nasal floor, palatal plane, and occlusal plane, however these measurements were not significantly related to the angle of septum deviation. The angle of septum deviation was not significantly correlated with the width of the nasal passage or lateral nasal wall angle, where we would have predicted that if the nasal septum was deviated more to one side, the facial features would also have been significantly deviated to that side. While we elected to pick the most deviated point along the nasal septum to represent the angle of septum deviation, future experimentation should consider assessing the nasal septum deviations along multiple points of the septum, utilization of volumetric measurements to better represent nasal air passage volume and how it is related to facial asymmetry, or a longitudinal study design to better understand the relationship between septal deviations and uneven nasal breathing with asymmetric facial growth.

The thesis of Alison Marie Lemkuil is approved.

Yong Kim

Jimmy Kuanghsian Hu

Sanjay M. Mallya, Committee Chair

University of California, Los Angeles

2024

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LIST OF ABBREVIATIONS

Abbreviation	Definition
ALW- L	Angle of Lateral Wall- Left
ALW- R	Angle of Lateral Wall- Right
ANF	Angle of the Nasal Floor
ASD	Angle of Septal Deviation
CBCT	Cone Beam Computed Tomography
DICOM	Digital Imaging and Communications in Medicine
DOME	Distraction Osteogenesis Maxillary Expansion
DNS	Deviated Nasal Septum
ENT	Ear Nose Throat Doctor, or Otolaryngologist
FH	Frankfort Horizontal Plane
INV	Internal Nasal Valve
NOSE	Nasal Obstruction and Symptom Evaluation Score
NPW-R	Nasal Passage Width- Right
NPW-L	Nasal Passage Width- Left
OP	Occlusal Plane
OSA	Obstructive Sleep Apnea
PP	Palatal Plane
RPE	Rapid Palatal Expansion

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I would like to acknowledge my research mentor and PI, Dr. Sanjay Mallya, for his extensive guidance on this project and expertise in the field of Radiology. Thank you very much for your time, energy, and insights throughout the completion of this project. I will carry the many valuable lessons I have learned from you regarding the importance of comprehensive radiological examination with me throughout my career in Orthodontics.

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Lastly, I would like to thank my family, co-residents, and fiancé Alex Layton for their guidance, assistance, and support during this project and throughout my time at UCLA. I could not have made it here without you.

INTRODUCTION

i. Facial Asymmetry

Facial symmetry describes a bilateral match in size, location, shape, and arrangement of each facial component in the sagittal plane [1]. However, it is important to note that perfect symmetry almost never exists in human anatomy, with only 2% of the world's population having perfectly symmetric faces [2]. Facial asymmetries may present in the vertical dimension, horizontal dimension, or in a combination of multiple dimensions, as depicted in Figure 1 [3].

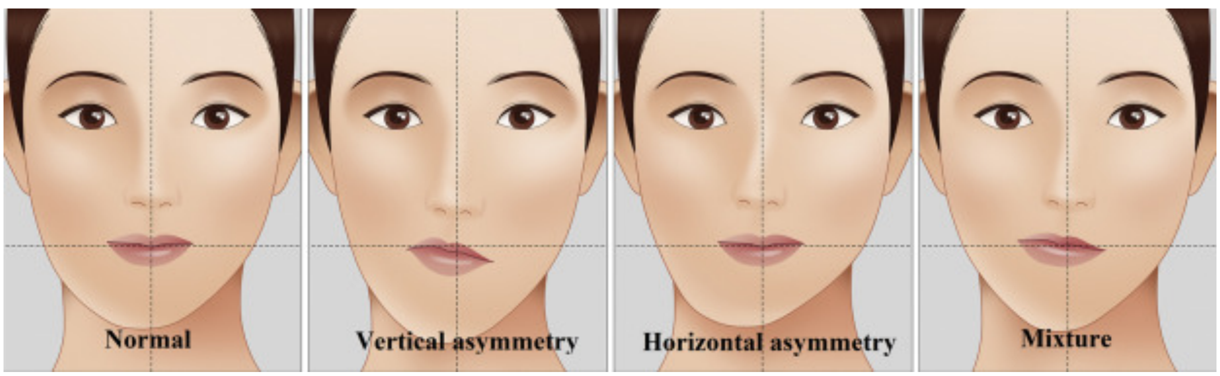

Figure 1. Types of Facial Asymmetry. Depiction of different types of facial asymmetries, such as vertical asymmetries, horizontal asymmetries, or a combination of both.

While one may assume that perfect facial symmetry would result in an increased perceived facial attractiveness, it has been demonstrated that perfect symmetry may be considered "disconcerting" to the general observer and a slight facial asymmetry is considered normal or esthetically preferred [1], [4]. Most asymmetries are mild enough that they are unperceived by the individual or others and present without any clinical implications. Discriminative thresholds for asymmetry detection vary for each facial feature, such as a nasal tip deviation of 4 mm or chin deviation of 6 mm [4], and if the deviation surpasses these thresholds the asymmetry will typically be noticed by the general observer.

The prevalence of orthodontic patients presenting with facial asymmetries clinically varies internationally, with 12 to 37% of patients in the United States presenting with asymmetry, 21 to 23% in Belgium, and 21% in Hong Kong [5]. The prevalence of orthodontic patients diagnosed with facial asymmetry dramatically increases when asymmetry is assessed by radiographic examination to an estimated prevalence of 50% [5]. As a result, radiographic examination offers an essential diagnostic tool for orthodontists when assessing patients with facial asymmetries to help quantify deviations that may otherwise be missed during the clinical exam.

Facial asymmetry may result from genetic or congenital causes, such as craniofacial conditions including hemifacial microsomia or cleft lip/palate; environmental causes such as facial trauma or infection; or functional factors contributing to facial asymmetry such as habits or occlusal interferences [6], [7], [8], [9]. Facial asymmetries can improve or worsen over time and have resulting symptoms depending on the severity of the asymmetry. While there is an extensive number of factors contributing to facial asymmetry, two significant aspects to consider are nasal septum deviations and uneven nasal breathing as represented by the internal nasal valve angle and cross-sectional area.

ii. Nasal Septum Deviations

A deviated nasal septum occurs when the thin wall between the nasal passages, known as the nasal septum, is displaced to one side of the nasal cavity (Figure 2) [10]. The septum is a thin bony-cartilaginous wall that divides the nasal cavity into two sides, and when severely deviated or shifted, may result in reduced nasal airflow and difficulty breathing. Traditional classification systems for nasal septum deviations may be assigned based on shape of the deviated septum or angle of septal deviation. Shape of the deviated septum is clinically relevant as nasal septa often do not deviate in a single direction, but rather deviate to one side and then the other. Deviated nasal septum shapes include C-shaped or reverse C-shaped, as well as S-shaped or reverse S shaped deviations in the anteroposterior and superior-inferior dimensions [11]. Other classification systems are dependent on angle of the nasal septum deviation, with mild deviation less than 9° of deflection, moderate between 9-15°, and severe deviations equal to or greater than 15° [12].

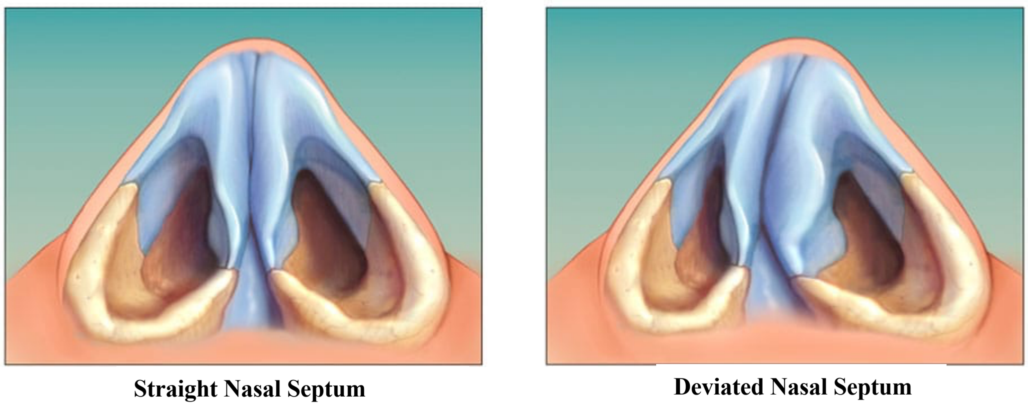

Figure 2. Examples of a Straight Nasal Septum Versus a Deviated Nasal Septum. In the image on the left, the nasal septum is straight and divides the nasal cavity into two even nasal passages. In the image on the right, the nasal septum is deviated, resulting in a constricted nasal passage on the patient's right and a larger nasal passage on the patient's left.

While most septal deviations result in no physical symptoms, possible clinical manifestation may include obstruction of one or both nostrils, nosebleeds, facial pain, snoring or sleep apnea, and awareness of the nasal cycle [10]. The nasal cycle is a normal physiological process controlled by the autonomic nervous system that results in alternate swelling of the inferior turbinates of the nose, resulting in congestion and decongestion of one nostril at a time [13]. This cycle assists with maintaining the moisture of the nasal cavity, protecting against respiratory allergies and infections, and possibly to optimize sense of smell [14]. While the nasal cycle is a continuously ongoing physiologic process, awareness or discomfort associated with this cycle is not normal and may result from the deviated nasal septum. Patients with severe septum deviations may resort to sleeping on one side to optimize breathing due to restricted airflow [10], [15], [16], but ultimately, definitive treatment for a nasal septum deviation requires surgery as a deviated septum is a structural issue. A septoplasty is the standard surgical procedure to correct a deviated nasal septum and is typically performed by an otolaryngologist, or an ear, nose, and throat (ENT) doctor. This surgery typically involves incision and straightening of the nasal septum, removal of the deviated bone and cartilage, and suturing the septum into place with placement of removable splints to hold the septum straight as it heals [17]. Thorough diagnosis and surgical management of septal deviations plays an imperative role in treating severe asymmetries and optimizing patient breathing.

iii. The Internal Nasal Valve (INV) and Previous Research

Another critical area of anatomy to be analyzed when diagnosing asymmetric nasal airway is the internal nasal valve (INV). During the process of inspiration, air enters through the vestibule of the nose, passes through the nasal valve, the nasal cavity, and into the nasopharynx [18]. The internal nasal valve is the narrowest part of the nasal passage bilaterally, as well as the narrowest cross-sectional area of the entire upper airway, and represents half of the total airflow resistance during inspiration [19] . This valve represents the point of maximum nasal airflow resistance during inspiration, rendering it an anatomical region of interest for nasal airway and nasal obstruction research [20].

The INV angle is measured between the nasal septum and the lateral cartilage of the nose, with an average value of 10° to 15° (Figure 3). In patients with a decreased internal nasal valve angle or decreased cross-section of this valve, the nasal airway will be restricted, contributing to greater resistance in airflow [20], [21]. Quantification of the internal nasal valve angle and cross-sectional area is invaluable for the diagnosis and treatment of severely constricted nasal airways.

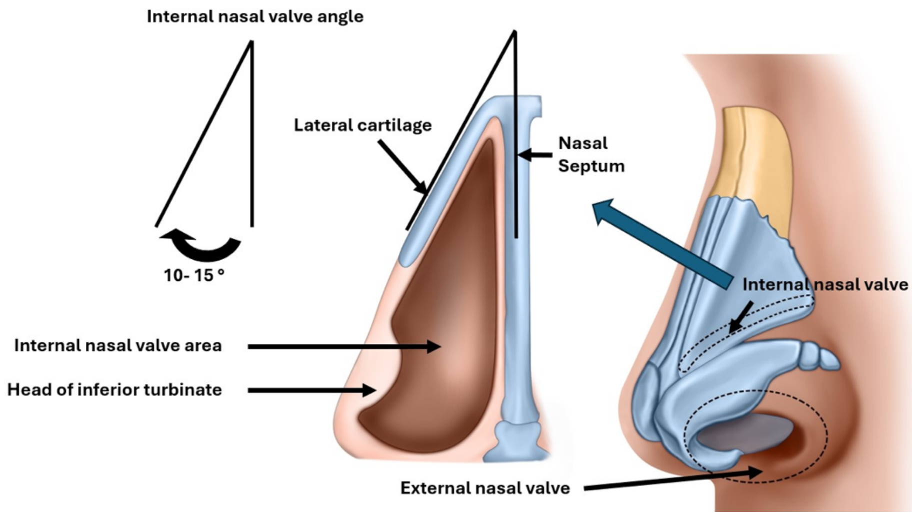

Figure 3. The Anatomy of the Internal Nasal Valve. This image demonstrates the anatomy and measurement of the internal nasal valve, which is located between the lateral cartilage of the nose and the nasal septum. A normal internal nasal valve angle is between 10-15°. Image credit to Dr. Audrey Yoon.

Cone-Beam Computed Tomography (CBCT) provides an essential 3-dimensional diagnostic tool for the analysis of nasal and facial asymmetries. Previous research has demonstrated that there is a significant relationship between nasal and facial growth asymmetry when comparing the absolute differences between the right and left sides of the face, and that the facial asymmetry is significantly associated with both the direction and amount of septal deviation [22]. However, weaknesses in this previous research includes comparison of two-dimensional analysis of facial asymmetry via Photoshop of extraoral photos with three-dimensional analysis of nasal asymmetry [22] . Asymmetries in facial depth could not be analyzed in this 2-dimensional data but likely represent key differences in facial growth and contribute to septal deviation. There remains a need to quantify the relationship between nasal and facial asymmetry using more accurate and precise quantification offered by CBCT analysis in all three planes of space.

Additional studies have demonstrated the importance of internal nasal valve measurements for orthodontic treatment. Research analyzing the INV before and after palatal expansion via Rapid Palatal Expansion (RPE) in orthodontic patients has demonstrated that patients' right and left INV angles and cross-sections increased significantly post-treatment [18]. This study also utilized subjective data, reported as the Nasal Obstruction and Evaluation Survey (NOSE) Score, to demonstrate patient's change in nasal airway symptoms before and after treatment. The results revealed that post-expansion, patients demonstrated a decreased NOSE score, reflecting an improvement in their nasal symptoms from moderate obstruction to mild obstruction [23]. Other studies have demonstrated how Distraction Osteogenesis Maxillary Expansion (DOME) improves the nasal airway by increasing the nasal floor width, and resultingly, increasing the INV [24]. While it is widely supported that palatal expansion improves oral airway such as seen in the reduction of symptoms for sleep apnea patients [18], this research provides evidence that palatal expansion may result in improved nasal airway as well.

This project offers enhanced understanding of how nasal septum deviations and asymmetric nasal breathing through the internal nasal valve contribute to facial asymmetry. Clinical applications and significance of these findings include analyzing how orthodontic appliances and otolaryngology treatments may contribute to improvement of oral and nasal airways, incorporating internal nasal valve angle and cross-sectional area in nasal airway analysis on CBCT, and ultimately helping patients breathe better and grow symmetrically through an enhanced understanding of the etiologies of nasal and facial asymmetry.

OBJECTIVES AND SPECIFIC AIMS

Objective: The objective of this study is to relate nasal septum deviations and asymmetric nasal airway with facial asymmetry for orthodontic patients diagnosed with deviated nasal septum on CBCT.

Specific Aims: We hypothesize that asymmetric breathing through the nose will affect facial asymmetry. Patients with significant nasal septal deviations, and as a result uneven nasal airway, will have significant facial asymmetry related to this deviation. We propose the following specific aims:

1) To quantify the internal nasal valve angle and internal nasal valve cross-sectional area using CBCT
2) To quantify the degree of nasal septal deviations
3) To analyze facial asymmetry using 3-dimensional CBCT data and relate extraoral asymmetry with nasal asymmetry from the data of internal nasal valve and septal deviations

DESIGN AND METHODOLOGY

i. Experimental Design

This study was a retrospective experiment analyzing the initial CBCT scans of 25 patients at the University of California Los Angeles Section of Orthodontics Clinic who were diagnosed with a deviated nasal septum on their initial UCLA Radiology report. The subject size of 25 patients was determined to be appropriate for our study based on similar experiments evaluating nasal or facial asymmetry using CBCT analysis with statistically significant findings [18], [22], [24], [25]. All radiology reports in the UCLA Orthodontics Dropbox folder from January 2023 to July 2024 were reviewed for significant findings of a deviated nasal septum (DNS). Key words utilized to scan the radiology reports and recruit subjects included: "septum", "deviated septum", and "is deviated".

Medical histories were reviewed using patient health history questionaries to rule out any medical conditions or history of nasal surgeries that may be confounding variables until the target size of 25 subjects was achieved. The following relevant inclusion and exclusion criteria were applied:

<u>Inclusion criteria:</u> Patients at the UCLA Orthodontics Clinic with a diagnosed deviated nasal septum on his or her initial radiology report, medically healthy patients who are age 12 years or older, no history of nasal surgeries or nasal trauma, and no reported history of orthodontic treatment.

<u>Exclusion criteria:</u> Patients younger than age 12, diagnosed with any craniofacial conditions or have reported history of nasal trauma or corrective surgery.

Our inclusion criteria evolved throughout the course of the study, as initially we had intended to include only patients who were done growing to eliminate the potential confounding variable of growth of subjects and its possible effect on nasal septum deviation. However, further literature review of this topic revealed that non-traumatic nasal septum deviations are evident in patients as early as age 7 years old, and the magnitude of these deviations is maintained throughout growth [26]. As many orthodontic patients are adolescents, we were required to include patients who were still growing but older than this key age of 7 years old to ensure that we reached our target number of subjects. We decided to set 12 years as our minimum age requirement as this age requirement eliminated patients who were presenting for phase I orthodontic treatment and instead included patients who were presenting for comprehensive treatment only.

ii. Data Collection

Orthodontic initial CBCT scans were analyzed using Dolphin Imaging software (version 11.95; Dolphin Imaging & Management Solutions, Chatsworth, CA) to provide 3-dimensional data relating nasal and facial asymmetry in coronal, sagittal, and transverse planes. As this was a retrospective study focusing on the relationship between nasal and facial asymmetry prior to orthodontic treatment, no progress radiographs after beginning treatment were required. Data collection was kept confidential, anonymized, and in compliance with HIPAA guidelines. After determining a subject to fit the relevant inclusionary criteria, the initial ortho CBCT digital imaging and communication in medicine (DICOM) files for each subject were uploaded to Dolphin if not already uploaded onto the patient's chart. Two examiners analyzed the CBCTs for data collection. Both examiners, including one orthodontic resident and one fourth year dental student, had extensive training in dentistry, radiology, and facial development prior to beginning this study.

Proper CBCT orientation was essential for this study to ensure consistent and reliable measurements, as inconsistent orientation of the images may result in a variety of measurements for the same anatomical areas of interest between different examiners. Each CBCT file was uploaded and oriented according to the Frankfort Horizontal (FH) plane, which is established from a lateral view by setting a plane from the anatomic points orbitale to porion as the horizontal axis [27]. After proper orientation of the DICOM file was achieved, the exact image "slice" was saved for analyses to ensure that each examiner was looking at the same sagittal, transverse, and coronal cross-sectional area as measurements vary significantly if you move through the image anteroposteriorly, superoinferiorly, or mediolaterally.

Consistent reference axes were also essential when taking measurements. Crista gali was utilized as a consistent y-axis for each patient, and the horizontal x-axis was determined to be a line 90 degrees from the y-axis.

Parameters to measure nasal asymmetry include angle of septal deviation (ASD), angle of nasal floor (ANF), angle of lateral nasal wall (ALW) on both the right (ALW-R) and left (ALW-L) sides, nasal passage width on the right (NPW-R) and left (NPW-L) sides, internal nasal valve angle on the right (INV angle-R) and left (INV angle-L), and internal nasal valve cross-sectional areas on the right and left. Definitions for each of the nasal asymmetry measurements can be found in Table 1.

These measurements can be analyzed from a coronal image cut, again with the y-axis established at crista gali and the x-axis as the horizontal line 90 degrees from the y-axis. An example of proper image orientation and nasal cavity measurements are as pictured in Figure 4.

Table 1. Definitions of Measurements for Nasal Asymmetry

Measurement:	**Definition:**
Angle of Septal Deviation (ASD)	The angle between the y-axis (the vertical line down from crista gali) and the most deviated point of the nasal septum
Angle of the Nasal Floor (ANF)	The angle between the x-axis (the horizontal line that is perpendicular to the line from crista gali) and the floor of nose
Angle of the Lateral Wall- Right and Left (ANF- R and ANF- L)	The angle between the y-axis and the widest portion of the nasal wall on each side. Typically, the most deviated portion of the nasal wall is lateral to the inferior turbinate
Passage width- Right and Left (PW- R and PW-L)	The width of the nasal passage measured from the y-axis to the most lateral point of the nasal cavity on each side
Internal Nasal Valve Angle- Right and Left (INV-R and INV-L)	The angle between the nasal septum to the most lateral point of the valve, as taken from the cross-sectional slice anteriorly to the beginning of the inferior turbinate
Internal Nasal Valve Area- Right and Left (INV area-R and INV area-L)	The cross-sectional area of the internal nasal valve on the right and left sides

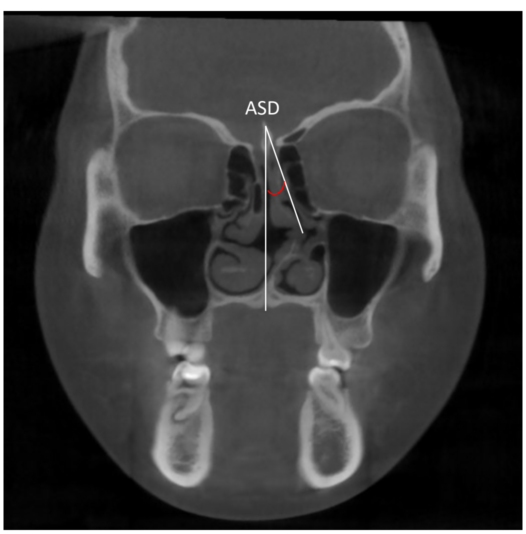

Fig. 4A

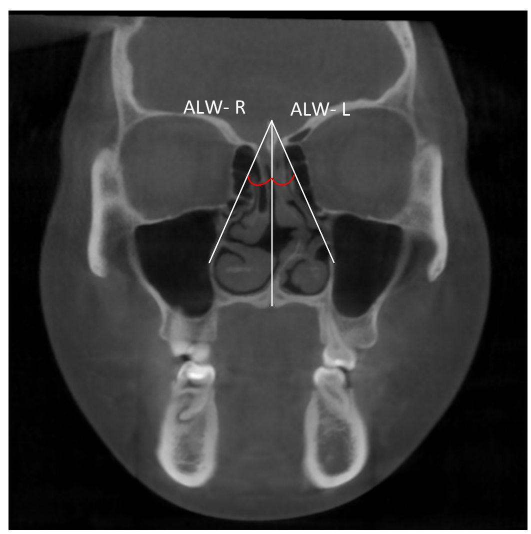

Fig. 4B

Fig. 4C

Fig. 4D

Figure 4. CBCT Measurements for Nasal Asymmetry. **Fig 4A**- Angle of nasal septum deviation measurements (°). **Fig 4B-** Angle of the lateral wall of the nasal cavity on the right and left (°). **Fig 4C-** The passage width of the nasal cavities on the right and left sides (mm). **Fig 4D-** Angle of the nasal floor relative to the horizontal plane . (°)

When assessing the internal nasal valve angle and cross sectional area, the orientation of the CBCT had to be modified as described by the protocol in Yoon et al in 2021 [18], as depicted in Figure 5A below. In this protocol the orientation of the CBCT file is rotated such that the dorsum of the nose is parallel to the horizontal plane and laterally into a sagittal view. The internal nasal valve measurements are demonstrated in Figure 5B, with the medial line tracing the nasal septum, to the soft tissue tip of the nose, and the lateral line tracing the lateral nasal cartilage parallel to the nasal septum. Figure 5C demonstrates the cross-sectional area of the internal nasal valve at this same cross-sectional slice.

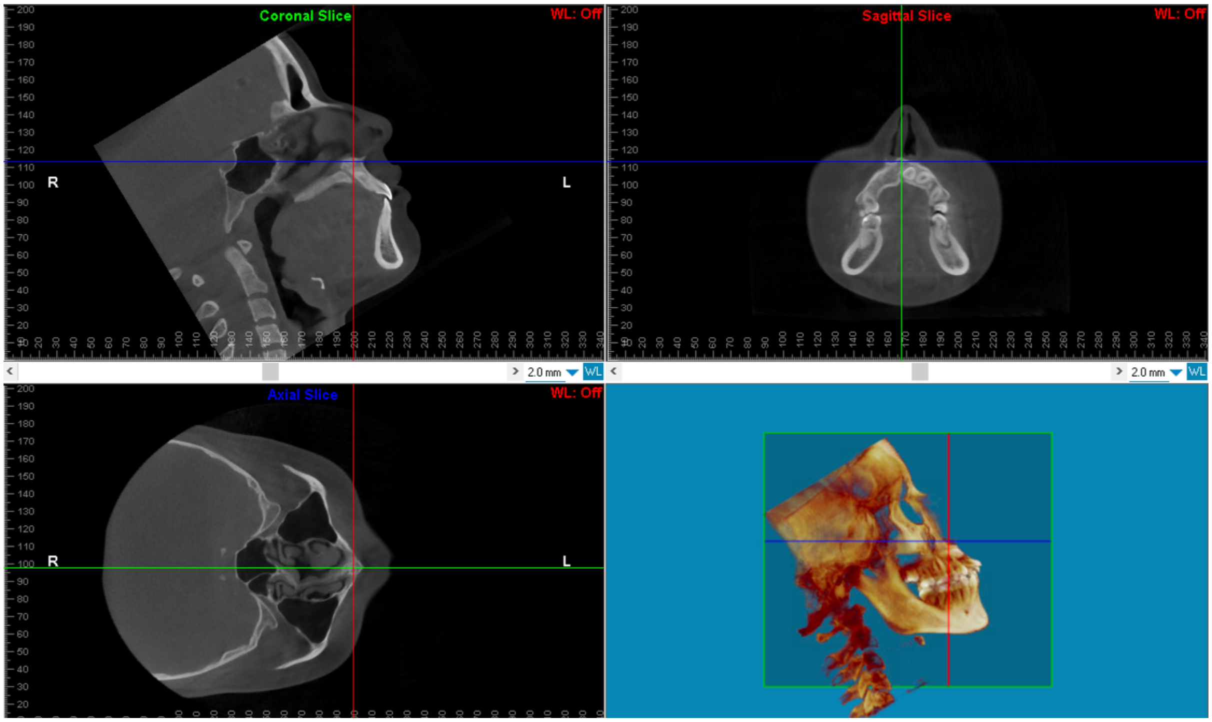

Fig. 5A

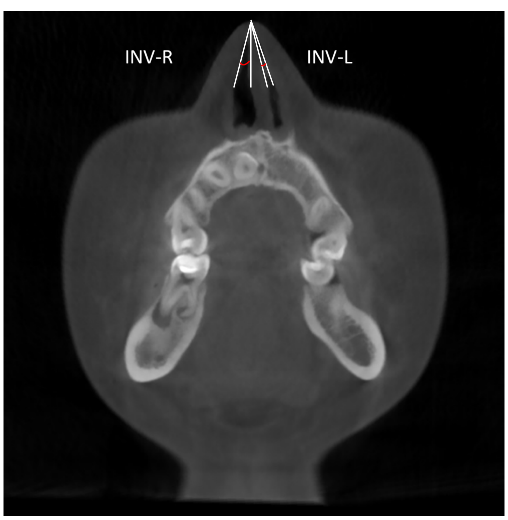

Fig. 5B

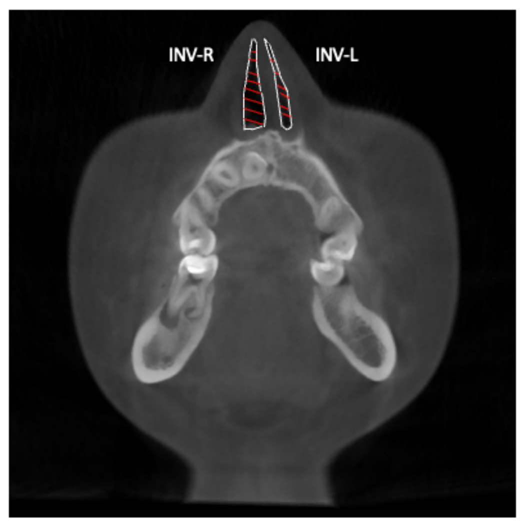

Fig. 5C

Figure 5. CBCT Measurements for the Internal Nasal Valve. **Fig 5A.** Modified hard tissue orientation of the CBCT for Internal Nasal Valve measurements. In this orientation the dorsum of the nose is oriented parallel to the horizontal plane, and the entire volume is rotated to a lateral view from the patient's right. This orientation best represents the direction of nasal airflow

through the internal nasal valve. **Fig 5B.** Internal nasal valve angles on the right and left sides (°). **Fig 5C.** Internal nasal valve cross-sectional areas on the right and left sides (mm^2).

Additional measurements of interests for facial asymmetry included palatal plane, occlusal plane, and chin deviation at menton. These landmarks were selected to assess for facial asymmetry because previous research has identified canting, or vertical asymmetry, and chin deviations as some of the most common facial asymmetries seen in orthodontic patients [28]. Definitions for measurements of facial asymmetry are listed in Table 2, and example of CBCT measurements for facial asymmetry are outlined in Figure 6. All 25 CBCTs were reviewed by both Examiner 1 and Examiner 2. A random number generator was utilized to select 5 CBCTs at random for each examiner to perform repeated measurements to assess intra-examiner reliability.

Table 2. Definitions of Measurements for Facial Asymmetry

Measurement:	**Definition:**
Palatal Plane	The angle between the x-axis and the best fit line for the palatal vault, determined by the most inferior points of the palate on the right and left sides of the palatal suture
Occlusal Plane	The angle between the x-axis and the best fit line between the first molar palatal cusp tips bilaterally
Chin Deviation at Menton	The angle between the y-axis and menton, the most inferior point of the mandible

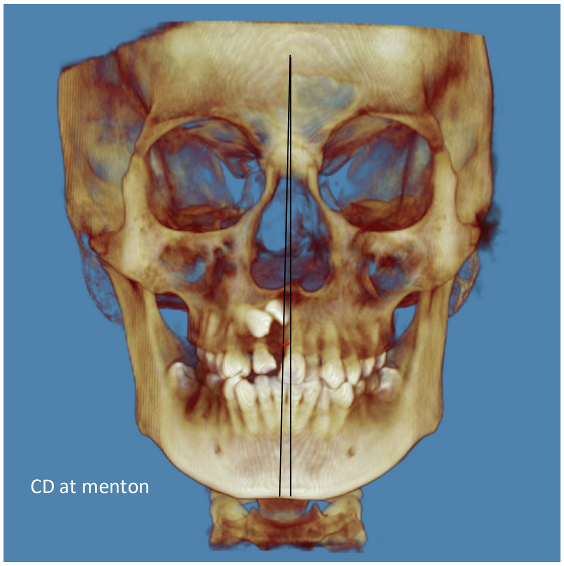

Fig. 6A

Fig. 6B

Fig. 6C

Figure 6. CBCT Analysis of Facial Asymmetry. **Fig 6A.** Angle of Chin Deviation at Menton relative to the vertical plane (°). **Fig 6B.** Angle of the palatal plane relative to the horizontal plane (°). **Fig. 6C.** Angle of the Occlusal plane at the palatal cusps of the first molar relative to the horizontal plane (°).

iii. Statistical Analysis

SPSS Software (Version 30.0; IBM Corp) was utilized for statistical analysis with remote statistical consulting provided by UCLA Statistical Methods and Data Analytics. Statistical analysis via Pearson's correlation was performed to assess significant relationships between two measurements of interest, reflecting both the magnitude and direction of the relationship.

The following equation was utilized to normalize the amount of deviations as a percentage relative to the entire nasal cavity, similar to the study performed by Kim et al [22]:

Difference between right and left distances or angles:

$$(Diff\ Rt - Lt)(\%) = 2(Rt - Lt) / (Rt + Lt) \times 100$$

Using this equation, a positive value would indicate a larger measurement on the right side, whereas a negative value would indicate a greater value on the left. Scatterplots were created to depict the data, and the best fit line on these graphs represented the correlation between two variables. Additionally, the intraclass correlation coefficient (ICC) was utilized to assess inter-examiner and intra-examiner reliability. 5 CBCTs were randomly selected by a number generator to be assessed by Examiners 1 and 2 a second time to assess for intra-examiner reliability. Expected outcomes included that the nasal asymmetry would correlate with the magnitude and direction of the facial asymmetry.

RESULTS

i. Description of the study sample

This study consisted of 25 patients treated at the UCLA Orthodontic Clinic who were diagnosed with a deviated nasal septum on their initial UCLA Radiology Report. The study sample's ages ranged from 12y7m to 50y1m, with an average age of 22y1m. In total 14 of the patients (56%) were female, while 11 patients (44%) were male. The angle of septal deviation varied from -17.4° to the left to 19.95° to the right, with a mean of 2.97°. The range of internal nasal valve angles for both sides was a minimum of 5.3° to a maximum of 19.8°, with a mean of 10.6°. The range of cross-sectional areas of the internal nasal valve for both sides was from 38.9 mm^2 to 153.2 mm^2, with a mean of 84.7 mm^2.

The angle of the nasal floor varied from -10.9° canted down to 9.85° canted up, with an average cant of -0.4° down. The angles of the lateral wall of the nasal cavity ranged from 16.3° to a maximum of 24.4°, with an average of 20.2°. The nasal passage widths ranged from 11.7 mm to 25.9 mm, with an average of 17.0 mm for the two sides. The angle of the palatal plane was a minimum of -8.4° down to 13.6° up, with an average angle of -0.3° down. The angle of the occlusal plane varied from a minimum of -4.2° down to a maximum of 2.4° up, with an average angle of -0.3° down. Lastly, chin deviation ranged from -2.9° to the left to 3.4° to the right, with a mean of 0.6° to the right. A comprehensive description of the study sample may be found below in Table 3.

Table 3. Description of the Study Sample

Variable	Result
Total Subjects	25

Sex	
Male	11 (44%)
Female	14 (56%)
Ethnicity	
African American	1 (4%)
Asian	4 (16%)
Caucasian	11 (44%)
Hispanic	8 (32%)
Middle Eastern	1 (4%)
Age	
Min - Max	12y7m -50y1m
Mean	22y1m
Median	18y0m
Angle of Septal Deviation	
Min - Max	-17.4° - 19.95°
Mean	2.97°
Internal Nasal Valve Angle	
Right-	
Min - Max	5.3° - 19.8°
Mean	10.4°
Left-	
Min - Max	6.1° - 17.5°
Mean	10.8°
Internal Nasal Valve Area	
Right-	
Min- Max	43.5 mm^2 – 153.2 mm^2
Mean	88.3 mm^2
Left-	
Min - Max	38.9 mm^2 – 142.6 mm^2
Mean	81.1 mm^2
Angle of the Nasal Floor	
Min - Max	-10.9° - 9.85°
Mean	-0.4°
Angle of the Lateral Wall	
Right-	
Min - Max	16.3° - 24.4°
Mean	20.3°
Left-	
Min - Max	17.4° - 23.7°
Mean	20.0°

Nasal Passage Width	
Right-	
Min - Max	14mm - 20.1mm
Mean	17.1 mm
Left-	
Min- Max	11.7mm- 25.9mm
Mean	16.8 mm
Chin Deviation at Menton	
Min - Max	-2.9° - 3.4°
Mean	0.6°
Angle of the Palatal Plane	
Min - Max	-8.4° - 13.6°
Mean	-0.3°
Angle of the Occlusal Plane	
Min - Max	-4.2° - 2.4°
Mean	-0.3°

ii. Correlations between Nasal and Facial Asymmetry

Correlations were first assessed maintaining positive and negative values for measurements of interest. As mentioned, the equation by Kim et al [22] was utilized to normalize the amount of deviations as a percentage relative to the entire nasal cavity, and in this equation a positive value represented a greater value on the right side or an upwards cant, while a negative value represented a greater value on the left side or a downwards cant.

The results revealed the following correlations, as outlined in Table 4 with 95% Confidence Intervals listed in Table 5. There was a negative correlation between the angle of septum deviation and the internal nasal valve angle ($r(23)= -.556$, $p= .004$), and a negative correlation between the angle of septum deviation and the internal nasal valve area ($r(23)= -.448$, $p=.025$). There were positive correlations between the angle of the nasal floor and the palatal plane ($r(23)= .829$, $p< .001$), the angle of the nasal floor and the occlusal plane ($r(23)= .405$, $p= 0.045$), the angle of the nasal floor and the passage width ($r(23)= .468$, $p= .018$), the palatal plane angle and the occlusal plane angle ($r(23)= .515$, $p= .008$), the palatal plane angle and the passage width (r(23)= .409, p= .042), and the internal nasal valve angle and internal nasal valve area (r(23)= .671, p< .001).

Table 4. Correlations of Nasal and Facial Asymmetry using average measurements from Examiner 1 and 2. Positive notes a deviation to the right or a cant upwards.

Correlations

		ASD	ANF	PP	OP	CD	ALW R-L	PW R-L	INV angle R-L	INV Area R-L
ASD	Pearson Correlation	--								
	N	25								
ANF	Pearson Correlation	.066	--							
	Sig. (2-tailed)	.755								
	N	25	25							
PP	Pearson Correlation	.060	.829**	--						
	Sig. (2-tailed)	.774	<.001							
	N	25	25	25						
OP	Pearson Correlation	.129	.405*	.515**	--					
	Sig. (2-tailed)	.538	.045	.008						
	N	25	25	25	25					
CD	Pearson Correlation	.329	.373	.098	-.249	--				
	Sig. (2-tailed)	.108	.066	.642	.231					
	N	25	25	25	25	25				
ALW R-L	Pearson Correlation	.066	-.120	-.147	-.377	.284	--			
	Sig. (2-tailed)	.753	.568	.482	.063	.168				
	N	25	25	25	25	25	25			
PW R-L	Pearson Correlation	.130	.468*	.409*	.133	.176	.122	--		
	Sig. (2-tailed)	.537	.018	.042	.525	.401	.560			
	N	25	25	25	25	25	25	25		
INV angle R-L	Pearson Correlation	-.556**	-.278	-.280	-.135	-.315	.038	-.167	--	
	Sig. (2-tailed)	.004	.178	.175	.520	.125	.858	.425		
	N	25	25	25	25	25	25	25	25	
INV Area R-L	Pearson Correlation	-.448*	-.152	-.317	-.003	-.128	-.082	.008	.671**	--
	Sig. (2-tailed)	.025	.468	.123	.989	.541	.696	.970	<.001	
	N	25	25	25	25	25	25	25	25	25

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 5. Confidence Intervals for Correlations of Nasal and Facial Asymmetry using average measurements from Examiner 1 and 2

Confidence Intervals				
			95% Confidence Intervals (2-tailed)	
	Pearson Correlation	Sig. (2-tailed)	Lower	Upper
ASD – INV Angle	-0.556	0.004	-0.780	-0.206
ASD – INV Area	-0.448	0.025	-0.717	-0.065
ANF – PP	0.829	<0.001	0.645	0.922
ANF - OP	0.405	0.045	0.011	0.690
ANF – PW R-L	0.468	0.018	0.090	0.729
PP - OP	0.515	0.008	0.151	0.756
PP – PW R-L	0.409	0.042	0.017	0.692
INV Angle – INV Area	0.671	<0.001	0.375	0.842

Next, the absolute values of all measurements were correlated to examine if the same relationships held when considering magnitude of the asymmetries independent of the direction. These correlations are reported in Table 6 with 95% Confidence Intervals listed in Table 7. The following additional correlations were evident when considering the magnitude of the deviations independent from the direction: the absolute value of chin deviation at menton was positively correlated with the absolute value of the angle of septal deviation ($r(23)= .403$, $p= .046$), and the absolute value of chin deviation at menton was positively correlated with the absolute value of the internal nasal valve angle ($r(23)= .527$, $p= .007$) .

Otherwise, similar positive correlations held true for the absolute value of the angle of septal deviation and the absolute value of the INV angle ($r(23)= .644$, $p < .001$), the absolute value of the angle of the nasal floor and the absolute value of the palatal plane angle(r(23)= .582, p= .002), and the absolute value of the internal nasal valve and absolute value of the internal nasal valve area (r(23)= .454, p= .023).

Table 6. Correlations of Nasal and Facial Asymmetry using absolute value of average measurements from Examiner 1 and 2.

		|ASD|	|ANF|	|PP|	|CD|	|OP|	|ALW|	|PW|	|INV angle|	|INV Area|
|ASD|	Pearson Correlation	--								
	N	25								
|ANF|	Pearson Correlation	-.014	--							
	Sig. (2-tailed)	.947								
	N	25	25							
|PP|	Pearson Correlation	-.114	.582**	--						
	Sig. (2-tailed)	.589	.002							
	N	25	25	25						
|CD|	Pearson Correlation	.403*	.151	-.143	--					
	Sig. (2-tailed)	.046	.471	.495						
	N	25	25	25	25					
|OP|	Pearson Correlation	.072	.074	-.007	.007	--				
	Sig. (2-tailed)	.733	.723	.972	.975					
	N	25	25	25	25	25				
|ALW|	Pearson Correlation	-.056	-.300	-.267	.109	.020	--			
	Sig. (2-tailed)	.792	.145	.198	.603	.924				
	N	25	25	25	25	25	25			
|PW|	Pearson Correlation	-.047	.329	.065	.392	-.078	-.127	--		
	Sig. (2-tailed)	.824	.108	.756	.053	.709	.546			
	N	25	25	25	25	25	25	25		
|INV angle|	Pearson Correlation	.644**	.217	-.007	.527**	-.243	-.055	.197	--	
	Sig. (2-tailed)	<.001	.298	.973	.007	.241	.793	.344		
	N	25	25	25	25	25	25	25	25	
|INV Area|	Pearson Correlation	.331	.098	.047	.050	-.152	.013	-.123	.454*	--
	Sig. (2-tailed)	.106	.642	.825	.811	.469	.953	.560	.023	
	N	25	25	25	25	25	25	25	25	25

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 7. Confidence Intervals for Correlations of Nasal and Facial Asymmetry using absolute value of average measurements from Examiner 1 and 2.

Confidence Intervals				
			95% Confidence Intervals (2-tailed)	
	Pearson Correlation	Sig. (2-tailed)	Lower	Upper
|ASD| - |CD|	0.403	0.046	0.009	0.688
|ASD| - |INV angle|	0.644	<0.001	0.334	0.828
|ANF| - |PP|	0.582	0.002	0.243	0.795
|CD| - |INV Angle|	0.527	0.007	0.167	0.763
|INV Angle| - |INV Area|	0.454	0.023	0.072	0.720

Scatterplots were generated to visualize the data, and significant correlations were represented by the best-fit line. Positive Pearson Correlation, or "r" values, indicates a positive correlation. As one value increased, the other increased in the same direction as well. A negative Pearson Correlation, or a negative "r" value indicated a negative correlation between two variables, suggesting that as one value increased the other decreased [29]. Positive "r" values had a positive slope for the best-fit line, as seen in Figure 7. Negative "r" values had a negative slope for the best-fit line, as seen in Figure 8.

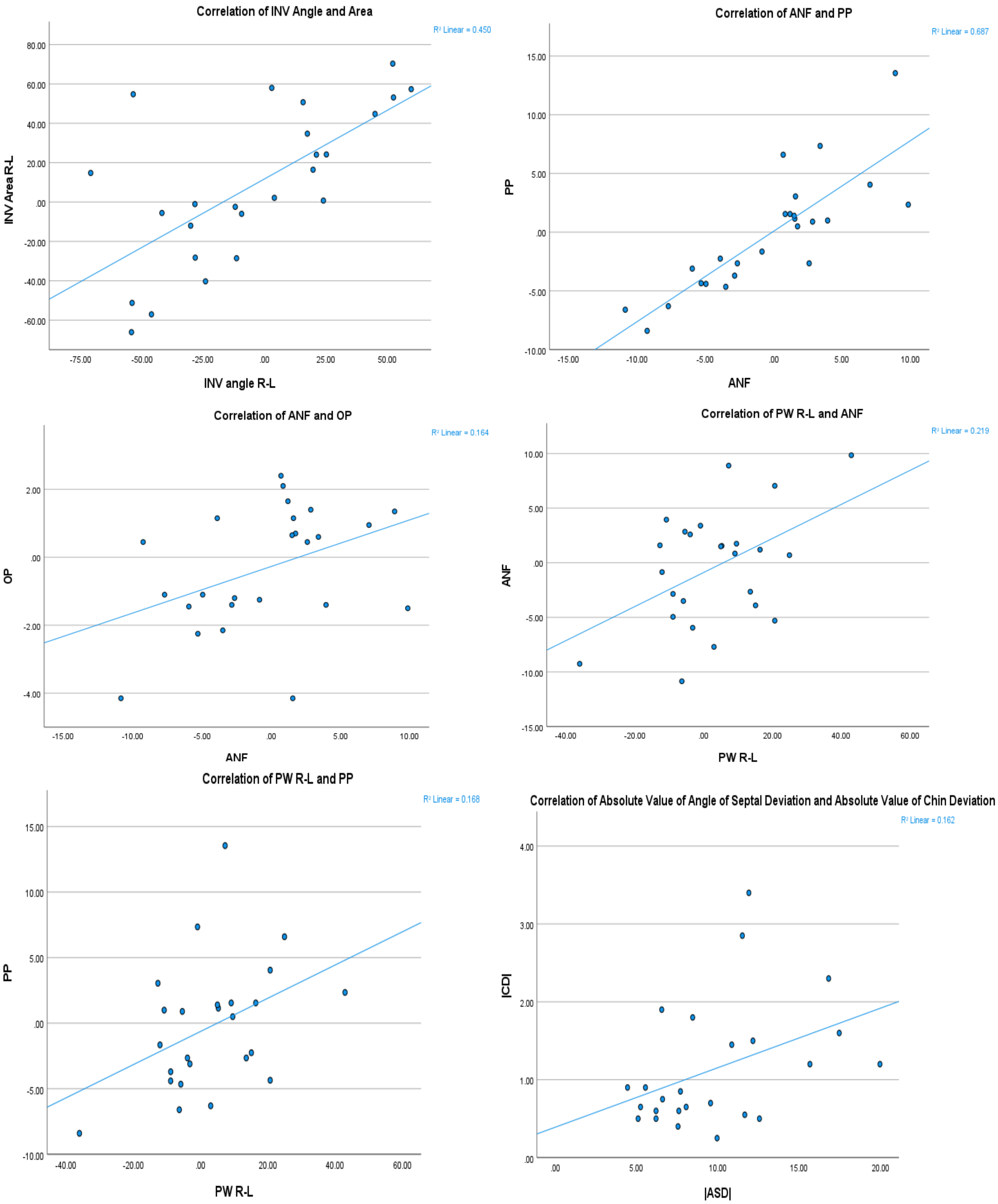

Figure 7. Positive Correlation Scatterplots. Scatterplots demonstrating positive correlations between INV Angle and INV Area, ANF and PP, ANF and OP, PW R-L and ANF, PW R-L and PP, and Abs ASD with Abs CD.

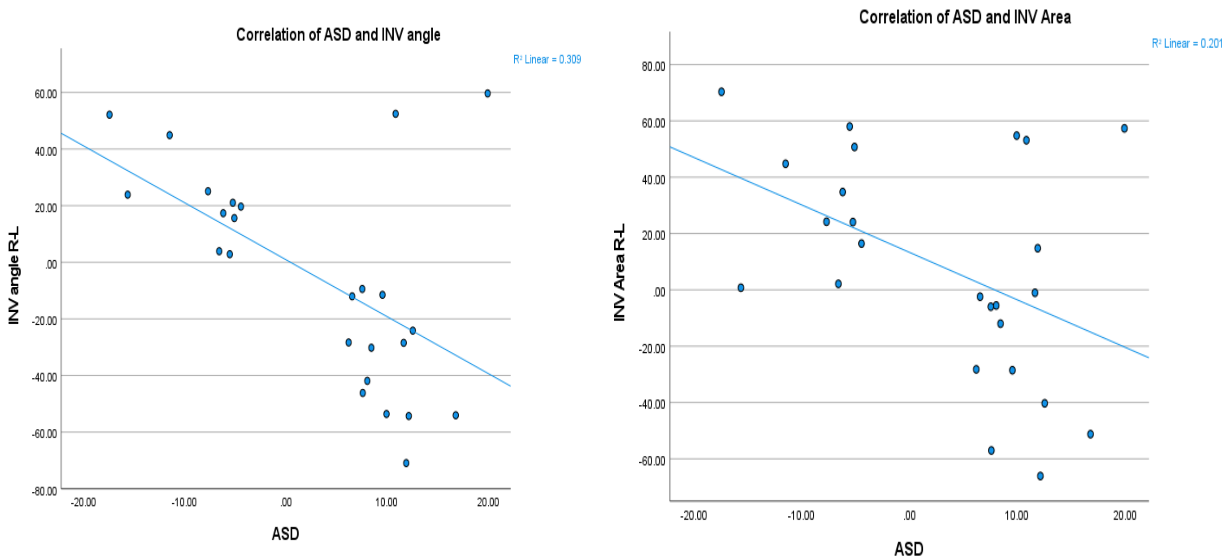

Figure 8. Negative Correlation Scatterplots. Scatterplots demonstrating negative correlations between ASD and INV angle and the negative correlation between ASD and INV area.

iii. Rater Reliability

Inter-rater and intra-rater reliability were assessed by the Intraclass Correlation Coefficient (ICC). This value assesses the reproducibility of the results to assess if consistent values were found between examiners and by the same examiner during repeated measurements.

ICC values were calculated for each measurement for intra-examiner reliability, as listed in Table 8. All values were above 0.9, which indicates excellent inter-examiner reliability[30]. 5 CBCTs were selected at random for repeated measurements, representing 20% of the total sample [26], and ICC values for intra-examiner reliability for Examiners 1 and 2 are listed in Tables 9 and 10. All values for intra-examiner reliability were also all above 0.9, indicating excellent intra-examiner reliability.

Table 8. Assessing Inter-Examiner Reliability: Intraclass Correlation Coefficient Values for Examiner 1 and 2

ICC:	**ASD**	**ANF**	**ALW R**	**ALW L**	**R PW**	**L PW**	**INV angle R**	**INV angle L**	**PP**	**OP**	**CD**
	0.99	0.977	0.947	0.963	0.98	0.994	0.944	0.982	0.996	0.981	0.982

Table 9. Intraclass Correlation Coefficient Values for Examiner 1

ICC:	ASD	ANF	ALW R	ALW L	R PW	L PW	INV angle R	INV angle L	PP	OP	CD
	0.995	0.99	0.957	0.927	0.99	0.99	0.99	0.986	0.999	0.996	0.99

Table 10. Intraclass Correlation Coefficient Values for Examiner 2

ICC:	ASD	ANF	ALW R	ALW L	R PW	L PW	INV angle R	INV angle L	PP	OP	CD
	0.993	0.99	0.988	0.953	0.976	0.986	0.998	0.995	0.999	0.998	0.97

DISCUSSION

Facial asymmetries present both functional and esthetic concerns. While minor asymmetries are not often perceived by the general observer and typically do not present with noticeable symptoms for the patient, more pronounced asymmetries may result in difficulties related to mastication, speech, and airway concerns in addition to compromised esthetics [31]. Nasal septum deviations often contribute to facial asymmetries and may inflict a significant burden on a patient's quality of life, commonly contributing to associated conditions such as obstructive sleep apnea, rhinosinusitis, and headaches [31]. As nasal breathing is so intrinsically dependent upon the anatomical structures of the upper respiratory tract, it is essential to consider how abnormalities or obstruction to nasal airflow may not only affect the process of breathing, but also may alter the growth and development of the neighboring anatomical structures.

The hypothesis of this study was that asymmetric breathing through the nose due to the constriction of the internal nasal valve by a deviated nasal septum would result in increased severity of facial asymmetry. The results of this experiment demonstrated a significant negative correlation between nasal septum deviation and the internal nasal valve. This negative correlation suggests that as the angle of septum deviation increased, the internal nasal valve angle and cross-sectional area decreased. This finding supports the relationship between the INV and nasal septum deviation that has been described in previous studies [18], [24], [32]. As the INV represents 50% of total airflow resistance, we utilized this anatomical landmark as in similar studies to represent the most significant barrier to nasal airflow [19], [20], [21] and attempted to correlate decreased INV measurements with changes in surrounding facial structures.

However, this study did not necessarily demonstrate the anticipated results on facial structures as seen in other studies [22]. The Kim et al study found correlations between deviated nasal septum and multiple horizontal measurements of soft tissue facial asymmetry. In our study, we found correlation with horizontal measurements as well, including the absolute value of the angle of septum deviation and absolute value of chin deviation at menton. However, the angle of septum deviation was not significantly correlated with the width of the nasal passage or lateral nasal wall angle. We would have predicted that if the nasal septum was deviated more to one side, the facial features would have also been significantly deviated to that side. This could be due to our sample population, or possibly due to our analysis using hard tissue landmarks whereas the previous study focused on soft tissue features and their relationship to deviated nasal septum. Additionally, our results may have varied from the findings of previous studies due to our protocol for measurement of angle of septum deviation, where the most deviated point of the septum was used. It is very common for septa to deviate in multiple directions, such as an “S” shaped or “C” shaped deviation, and thus the deviations might not be accurately defined by the most deviated point alone. While we elected to pick the point of most significant deviation along the nasal septum to keep our measurements consistent, future experimentation should consider assessing the nasal septum deviations along multiple points of the septum, analyzing the angle where the septum meets the palatal plane, or utilization of volumetric measurements to better capture nasal air passage volume and how it is related to nasal septum deviation.

We decided to assess the angle of the nasal floor and palatal region as previous studies had found septal deviation was associated with asymmetry primarily in the nasal floor and palate [33]. A link between these regions and septum deviation has been observed in cleft lip and palate patients, who commonly present with nasal septum deviations related to their palatal clefting [34]. The belief is that the nasal septum has higher growth potential than the adjacent facial regions, and for cleft patients, the cleft face becomes increasingly more asymmetric when the nasal septum is deviated to one side because the muscles are only attached to that side. The septum therefore deviates to the non-cleft side as a result of unopposed muscle pull. Asymmetric facial growth will continue for these patients unless the septum is surgically placed in the facial midline and the nasolabial muscles are reattached symmetrically. In our healthy population, our findings demonstrated positive correlations between the angle of the nasal floor, palatal plane, and occlusal plane, however they were not significantly related to the angle of septum deviation.

The results revealed that when one side of the nasal passage was larger than the other, there was a correlation with nasal and palatal plane canting. When the right side of the nasal passage was larger, there was an upward cant of the nasal and palatal planes. When the left side of the nasal passage was larger, there was a downward cant of the nasal and palatal planes. However, interestingly this canting was not related to the angle of septal deviation. These findings could be due to our selection of the point of angle of septum deviation, as we decided to focus on the most deviated portion of the septum rather than looking at the angle at which the septum meets the floor of the nose. Clinically, canting of the occlusal plane relative to the face is a helpful tool to visually assess for skeletal asymmetry [35], [36], as well as obvious bilateral mismatch when comparing the left and right sides of an individual's anatomy. Future experimentation should therefore examine the angle at which the nasal septum meets the floor of the nose on each side of the nasal cavity and examine if this angle is correlated with the canting of the nasal floor and palatal plane, as this could be helpful for clinical diagnosis.

We decided to repeat the analyses a second time utilizing the magnitude of the asymmetries independently from the direction of said asymmetries by running a correlation analysis using the absolute value for all measurements of interest. When doing so, we found that the magnitude of chin deviation correlated significantly with the magnitude of septal deviations.

According to a foundational study by Severt and Proffit, chin deviation is the most common feature of facial asymmetry [28]. While some studies have reported an increased chin deviation to left (70-90%), ours did not show such an increase in prevalence, similar the results the Jialing et al study, possibly due to our population [37]. Additionally, our results revealed that the absolute value of chin deviation was positively correlated with the internal nasal valve angle, suggesting that patients with increased chin deviation may have increased INV angle. However, since the directionality of the measurement is lost by running the analysis of the absolute value of the measurement, it is unclear if this relationship holds true for both sides of the internal nasal valve rather than just an increased internal nasal valve on one side.

Limitations of this experiment include its inability to distinguish between correlation and causation of nasal and facial asymmetry, issues related to utilization of crista gali as the y-axis, human error in CBCT analysis, depending on the mean values of two examiners as anatomical truth values, as well as limitations related to our study sample. First, the retrospective design of this experiment inhibits the ability to determine causality related to nasal septum deviations and facial asymmetry. The question “which came first: the nasal septum deviation or the facial asymmetry?” is unable to be answered by this experimental design which instead focuses on establishing correlation between the two measurements, not the causation. Age was not considered as a significant factor in these analyses, as instead we were focusing on determining the correlation of nasal and facial asymmetry regardless of the snapshot of time or the patient’s age at which the initial CBCT scan was taken. However, some studies argue that the chance of deviation of the nasal septum increases with age, specifically finding that every 10-year age increase resulted in an increased odd of septal deviation by 0.32 [38] but there is also the confounding factor of increased risk of nasal trauma with increased age. This highlights another limitation to this study which is that it is difficult to isolate cases of nasal septum deviation that occurred during the time of development as opposed to deviations that happened after the fact. Nasal septum deviations that happened after the time of facial growth and development would be unlikely to contribute to development of facial asymmetry, and therefore inclusion of patients with septum deviations that occurred after facial development would negatively affect the correlation between septum deviation and facial asymmetry. While our exclusion criteria was specific for patients with nasal or facial trauma to mitigate this issue, there is no way to be certain that any of the septum deviations observed on CBCT occurred during the time of development.

Our study used crista gali as the y-axis, and thus our results were based on the assumption that cristal gali is a true vertical. However, crista gali may be tilted or curved instead of being straight vertically, and a deviated crista gali may not be the best representation of the vertical axis of the entire image. Additionally, error between examiners may have resulted from establishment of different y-axes in cases of non-linear crista gali.

Human error during CBCT analysis is another potential limitation of our study. To try to diminish this error, we spent months training examiners how to use the Dolphin imaging software, the establishment of proper CBCT orientation, consistent slice selection, and identification of key anatomical areas of interest. Overall, we were able to achieve excellent intra-examiner and inter-examiner reliability as defined by the ICC values which were all greater than 0.9. Yet, a limitation of this study stems from the fact that the mean values of both examiners were utilized as the anatomical truth values. It is possible that error was present in these measurements and as a result the mean values for each measurement could have some error as well.

Lastly, some limitations of this study may arise from our study sample. This study focused on patients with deviated nasal septum as diagnosed on the UCLA Radiology Report, therefore only focusing on patients with a deviated nasal septum diagnosis yet no reported history of nasal trauma, nasal surgeries, or craniofacial conditions that may be associated with deviated septa. These deviations were technically an incidental finding, as the purpose of the CBCTs were for initial orthodontic records rather than screening for nasal septum deviations. It may be argued that this population is fairly representative of the general population presenting with a nasal septum deviation who may have been previously unaware of the deviation due to lack of severity of the symptoms, but this sample may not be completely representative of the general population as a whole.

Consideration of deviated nasal septum diagnoses on radiology reports of our study sample led us to an interesting question: if much of the general population has a slight deviation of the septum, when is a deviated septum considered "significant?" Ultimately, our research concluded that there is a universal lack of concordance related to diagnosis of nasal septum deviations due to the multitude of classification systems available, some related to the shape of the septum such as the Mladina's classification [38], the angle of deviation [12], or a combination of the two [26]. This lack of consistency in diagnosis of nasal septum deviations explains the vast discrepancies in prevalence of deviated nasal septum, with some estimates of roughly 1%-55% of different age groups having a deviated septum, while other studies report a prevalence of nearly 90% of adults having a deviated septum [38]. This lack of consensus may potentially result in undiagnosed cases, and as such, the establishment of a consistent universal classification system for nasal septum deviation diagnosis would help standardize diagnosis and prevalence of nasal septum deviations.

Based on our findings, we propose a set of future directions to enhance our understanding of the complex relationship between facial and nasal asymmetry. Incorporation of volumetric measurements, such as incorporation of CBCT segmentations of the nasal septum or nasal passageways, would enable investigation into how changes in nasal air passage volume may affect facial asymmetry. Future experimentation should consider nasal septum shapes including incorporation of various data points along the nasal septum and measurement of the angle at which the septum meets the palatal plane. Additionally, functional analysis may be utilized to better assess the role of asymmetric breathing through the non-stationary nasal airway. Longitudinal studies or studies assessing effects of orthodontic treatment on nasal and facial asymmetry would be beneficial to understanding how these asymmetries progress over time or as a result of treatment. Lastly, consistent classification systems for nasal septum deviations must be incorporated into clinical practice to better assess prevalence of septum deviations. Ultimately, with widespread utilization of CBCT, dentists are in a potential position to help make an appropriate referral to an ENT or airway specialist in cases of severe deviations, and standardizing the diagnosis protocol could help many patients receive the treatment they need.

CONCLUSIONS

In conclusion, the null hypothesis that nasal asymmetry was correlated with the magnitude and direction of facial asymmetry was supported for some measurements but not others.

We conclude the following:

- Facial asymmetries present both functional and esthetic concerns.
- It is essential to consider how abnormalities or obstruction to nasal airflow may affect the process of breathing and alter the growth and development of the neighboring anatomical structures.
- There was a negative correlation between nasal septum deviation and the internal nasal valve. This negative correlation suggests that as the angle of septum deviation increased, the internal nasal valve angle and cross-sectional area decreased.
- The angle of septum deviation was not significantly correlated with the width of the nasal passage or lateral nasal wall angle.
- There was a positive correlation between the angle of the nasal floor, palatal plane, and occlusal plane, however these measurements were not significantly related to the angle of septum deviation.
- When the right side of the nasal passage was larger, there was an upward cant of the nasal and palatal planes. When the left side of the nasal passage was larger, there was a downward cant of the nasal and palatal planes. The magnitude of canting was not positively correlated to the amount of septal deviation.
- The magnitude of chin deviation was significantly correlated with the magnitude of septal deviations.

- Future studies incorporating various points of nasal septum anatomy and nasal breathing functions are necessary to further understand the relationship between septal deviations and uneven nasal breathing with asymmetric facial growth.
- With widespread utilization of CBCT, dentists are in a potential position to help make an appropriate referral to an ENT or airway specialist in cases of severe deviations.

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