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THE INFLUENCE OF MAXILLOFACIAL SKELETAL MORPHOLOGY ON AIRWAY DIMENSIONS AND ASSOCIATED ENT DISORDERS IN PEDIATRIC PATIENTS.

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Abstract

Background: Optimal upper airway function is essential for normal pediatric craniofacial development and overall health. While common ENT disorders like Obstructive Sleep Apnea (OSA) and adenotonsillar hypertrophy are known causes of airway obstruction, the reciprocal influence of underlying maxillofacial skeletal morphology—specifically, deviations in the maxilla and mandible—on airway dimensions remains a critical area requiring precise quantification.

Objective: This study aimed to quantitatively analyze the correlation between specific three-dimensional (3D) maxillofacial skeletal variables and volumetric airway dimensions in a pediatric cohort, and to compare these airway measurements across distinct clinical ENT diagnostic groups.

Methods: A retrospective cross-sectional analysis was performed on Cone-Beam Computed Tomography (CBCT) scans and medical records of pediatric patients 46. Standardized 3D landmark analysis was used to measure key skeletal parameters. The upper airway was segmented and quantified for Nasopharyngeal Volume (NPV), Oropharyngeal Volume (OPV), and the Minimum Cross-Sectional Area (MCA). Patients were categorized into three groups: No ENT Issues, Adenoid/Tonsil Hypertrophy, and Diagnosed OSA. Statistical analyses included Pearson's correlation, ANOVA, and Multiple Linear Regression.

Results: Significant negative correlations were found between specific skeletal patterns and airway dimensions. Specifically, mandibular retrognathia (increased ANB angle) showed the strongest negative correlation with both OPV ($r = -0.65$, $p < 0.001$) and MCA ($r = -0.71$, $p < 0.001$). Furthermore, the OSA group exhibited significantly reduced mean OPV and MCA compared to both the No ENT Issues group and the Hypertrophy group ($p < 0.01$). Regression analysis confirmed that the ANB angle was the most significant independent predictor of reduced oropharyngeal airway volume, even when controlling for soft tissue factors.

Conclusion: Specific maxillofacial skeletal patterns, particularly those indicative of mandibular retrognathia and increased vertical growth, constitute a significant anatomical predisposition to reduced upper airway dimensions in children. This skeletal compromise is strongly associated with common pediatric ENT disorders, especially OSA. These findings advocate for the inclusion of early, detailed 3D skeletal and airway assessment in the collaborative management protocols between Dental/Orthodontic and ENT specialists to facilitate proactive intervention and improve long-term respiratory health.

Keywords: Maxillofacial Morphology, Pediatric Airway, Obstructive Sleep Apnea (OSA), Mandibular Retrognathia, CBCT, Interdisciplinary Care.

Introduction

The intricate process of pediatric craniofacial growth is profoundly influenced by environmental and functional factors, most critically by the mode of respiration. The upper airway, spanning the nasal cavity, nasopharynx, oropharynx, and hypopharynx, serves not only as the primary conduit for respiration but also as a physical constraint and dynamic determinant of skeletal development. Disruptions to this vital system during childhood—the peak period of craniofacial maturation—can initiate a cascade of morphological and functional adaptations, leading to both maxillofacial skeletal deviations and a range of debilitating Ear, Nose, and Throat (ENT) disorders.

The Critical Interdependence of Airway Function and Skeletal Development: The concept of a balanced skeletal-airway complex is fundamental to understanding pediatric health. Ideally, the maxilla and mandible, along with associated craniofacial structures, develop in harmony with the necessity for unobstructed, obligate nasal breathing. Disturbances to this pattern, often stemming from anatomical obstructions like adenoid or tonsil hypertrophy, chronic rhinitis, or allergic inflammation, force a shift toward chronic mouth breathing. This altered respiratory function exerts powerful biomechanical forces on the growing facial skeleton. Chronic mouth breathing is strongly associated with the development of the so-called "adenoid facies," characterized by a narrower maxilla, increased anterior facial height (high-angle pattern), and a more posteriorly positioned mandible (retrognathia). These skeletal changes, while often addressed purely for aesthetic or occlusal reasons in orthodontics, simultaneously contribute to a vicious cycle by physically reducing the very dimensions of the upper airway. Specifically, mandibular retrognathia reduces the space available in the oropharynx and hypopharynx, while a constricted maxilla reduces the capacity of the nasal cavity and nasopharynx. Understanding this bidirectional influence—where ENT pathology influences skeletal growth, and skeletal morphology influences airway patency—is central to effective interdisciplinary management.

Airway Obstruction and Associated Pediatric ENT Disorders: The clinical manifestation of reduced airway dimensions during childhood is diverse and carries significant morbidity. Obstructive Sleep Apnea (OSA) is perhaps the most serious outcome, affecting up to \$5.7\%\$ of children. Pediatric OSA is characterized by recurrent episodes of partial or complete upper airway obstruction during sleep, leading to fragmented sleep, intermittent hypoxemia, and hypercapnia. The long-term consequences are severe, spanning neurocognitive deficits (e.g., poor attention and academic performance), behavioral problems, cardiovascular dysfunction, and growth failure. While the primary cause of OSA in young children is often lymphoid hypertrophy (adenoids and tonsils), a persistent skeletal constraint can remain a significant residual factor even after surgical removal. Furthermore, chronic upper airway compromise is linked to other common pediatric ENT diagnoses, including recurrent otitis media with effusion (OME) due to compromised Eustachian tube function resulting from nasopharyngeal obstruction, and the perpetuation of allergic or infectious rhinosinusitis due to poor ventilation and drainage. Therefore, the simple measurement of airway space serves as a critical biomarker for a spectrum of pediatric ENT morbidity.

Methodological Advancements in Airway Assessment: Traditionally, the relationship between skeletal patterns and the airway was studied using two-dimensional (2D) lateral cephalograms. While effective for angular and linear skeletal measurements, 2D imaging inherently suffers from projection errors, superimposition of structures, and the inability to accurately assess the true volumetric capacity and three-dimensional (3D) geometry of the pharyngeal airway. This limitation has historically led to an incomplete or under-recognized depiction of airway compromise. The advent of Cone-Beam Computed Tomography (CBCT) has revolutionized this assessment. CBCT provides high-resolution, volumetric data, allowing for precise quantification of the total volume and the identification of the minimum cross-sectional area (MCA)—the narrowest and most clinically relevant point of obstruction. Utilizing CBCT allows for a rigorous and repeatable analysis, bridging the gap between anecdotal clinical observations and objective, quantitative evidence regarding the skeletal contribution to airway impairment.

Rationale and Study Objectives: Despite the established clinical correlation, few studies have concurrently analyzed comprehensive 3D maxillofacial skeletal morphology alongside precise volumetric airway measurements in a single pediatric cohort with existing ENT diagnoses. Existing literature often focuses on single skeletal parameters or relies on less precise 2D measurements. A definitive interdisciplinary study is needed to provide quantitative data that will inform standardized clinical protocols.

Materials and Methods

Study Design

This was a **retrospective, cross-sectional, comparative study** utilizing pre-existing patient records and Cone-Beam Computed Tomography (CBCT) images collected as part of routine dental or ENT diagnostic work-up.

Study Population

The sample consisted of **46 pediatric patients** (mean age 9.5 \pm 2.1 years; range 7–13 years) who had undergone CBCT scanning at GIMSH between 2018 and 2019.

Inclusion Criteria:

- Age between 7 and 13 years.
- Availability of high-quality CBCT images encompassing the cranium, maxillofacial structures, and the entire upper airway (from the nasal floor to the cervical vertebrae C4).
- Complete dental and ENT records documenting clinical history and diagnosis.

Exclusion Criteria:

- Presence of known craniofacial syndromes or congenital anomalies (e.g., Cleft Lip/Palate, Crouzon syndrome).
- History of previous maxillofacial surgery, orthodontic treatment (beyond simple retainers), or airway surgery (e.g., adenotonsillectomy) that could alter skeletal morphology or airway space.
- Poor image quality (e.g., motion artifacts) or non-standardized head positioning during scanning.

Group Classification

Patients were divided into three clinical groups based on their documented ENT status:

1. **Group 1: Control/No Issues (n=16):** Patients with no documented history or current diagnosis of chronic upper airway obstruction or related ENT pathology.
2. **Group 2: Adenoid/Tonsil Hypertrophy (n=15):** Patients diagnosed with chronic upper airway obstruction secondary to Grade 3 or 4 adenoid or tonsil hypertrophy, or both.
3. **Group 3: Obstructive Sleep Apnea (OSA) (n=15):** Patients with an established diagnosis of OSA confirmed by a polysomnography (PSG) test, with an Apnea-Hypopnea Index (AHI) greater than 1.0 event/hour.

Image Acquisition and Standardization

CBCT Imaging

All images were acquired using the same CBCT unit [Insert CBCT Unit Name and Manufacturer] with consistent settings: [Specify kVp (120 kVp)], [Specify mA (5.0 mA)], exposure time [18 seconds], and a voxel size of [0.3 mm].

Patient Positioning

During scanning, all patients were positioned according to the standard operating procedure: seated upright, Frankfort Horizontal plane parallel to the floor, teeth in maximum intercuspation, and instructed to hold their breath for a moment to minimize motion artifacts and to swallow once before the scan to standardize **tongue position** within the oral cavity.

Image Processing

The Digital Imaging and Communications in Medicine (DICOM) files were exported and imported into specialized 3D cephalometric and rendering software, Specify Software Name, Dolphin Imaging 11.9 or Mimics Innovation Suite.

Maxillofacial Skeletal Measurements (Independent Variables)

Skeletal analysis was performed after orienting the 3D volume to the **Natural Head Position (NHP)**, defined by setting the Frankfort Horizontal Plane (Porion-Orbitale)}$ parallel to the horizontal plane. Key cephalometric landmarks were identified, and the following 3D skeletal parameters were measured:

- **Anteroposterior Relationship:**
  - **ANB Angle:** Maxilla to mandible relationship.
  - **Wits Appraisal:** Perpendicular distance from Point A and Point B to the Occlusal Plane.
- **Vertical Relationship:**
  - **Maxillary Plane-Mandibular Plane Angle (MP-SN Angle):** A measure of vertical growth pattern (high-angle vs. low-angle).
  - **Posterior Facial Height (Sella-Gonion) / Anterior Facial Height (Nasion-Menton) Ratio:** Used to classify facial types (dolichofacial downarrow vs. brachyfacial uparrow).
- **Mandibular Position:**
  - **SNB Angle:** Anteroposterior position of the mandible relative to the cranium.

Airway Dimensional Measurements (Dependent Variables)

The upper airway was segmented and analyzed using the volume rendering tools within the software. Airway boundaries were defined by a fixed {Hounsfield Unit (HU)} threshold to differentiate air from surrounding soft tissues and bone.

The airway was divided into three clinically relevant anatomical regions using defined horizontal planes:

1. **Nasopharyngeal Airway Volume (NPV):** Defined superiorly by the plane passing through the most anterior point of the Sella Turcica and inferiorly by the plane passing through the posterior nasal spine PNS.
2. **Oropharyngeal Airway Volume (OPV):** Defined superiorly by the PNS plane and inferiorly by the plane passing through the most inferior point of the epiglottis.
3. **Total Airway Volume (TAV):** Sum of NPV + OPV.
4. **Minimum Cross-Sectional Area (MCA):** The narrowest 2D area measured perpendicular to the airway long axis within the oropharynx, identifying the choke point of potential obstruction.

Reliability Assessment

All measurements were performed by a single calibrated examiner ([Author Initials], e.g., JM). To determine intra-rater reliability, the examiner re-measured all 3D skeletal and airway parameters on **10 randomly selected CBCT scans** after a minimum wash-out period of two weeks. Reliability was assessed using the **Intraclass Correlation Coefficient (ICC)**, with values greater than 0.80 considered indicative of high reliability.

Statistical Analysis

Statistical analysis was performed using [Specify Software, e.g., SPSS version 26.0. The level of significance was set at alpha = 0.05.

- **Descriptive Statistics:** Means and standard deviations were calculated for all continuous variables (age, skeletal dimensions, airway dimensions).
- **Normality:** The Shapiro-Wilk test was used to check the distribution of the data.
- **Correlation Analysis: Pearson's Correlation Coefficient** was calculated to determine the strength and direction of the linear relationship between continuous skeletal parameters and airway dimensions (NPV, OPV, MCA).
- **Group Comparisons: One-way Analysis of Variance (ANOVA)** was used to compare the mean airway dimensions (NPV, OPV, MCA) across the three clinical groups (Group 1, 2, and 3). Post-hoc analysis using the **Tukey's HSD test** was applied to identify specific differences between group pairs.
- **Prediction Modeling: Multiple Linear Regression** analysis was performed to identify the independent skeletal variables that best predicted the reduced OPV and MCA, controlling for potential confounding factors such as age and gender.

Results

The analysis included data from **46 pediatric subjects** (25 male, 21 female), with a mean age of 9.5 \pm 2.1 years. The sample was successfully categorized into three clinical groups: Control/No Issues (n=16), Adenoid/Tonsil Hypertrophy (n=15), and Diagnosed Obstructive Sleep Apnea (OSA) (n=15).

Reliability Assessment and Descriptive Statistics

The intra-rater reliability analysis for all 3D skeletal and airway measurements yielded high **Intraclass Correlation Coefficient (ICC)** values, ranging from 0.88 to 0.96 ($p < 0.001$). This confirms the consistency and precision of the measurement protocol.

Table 1 summarizes the mean and standard deviation (SD) for the key maxillofacial skeletal parameters and the measured airway dimensions for the entire cohort.

Variable	Mean (± SD)	Unit	Interpretation
Skeletal Variables			
ANB Angle	4.2 \pm 2.8	Degrees	Avg. Class II tendency
SNB Angle	77.8 \pm 3.5	Degrees	Avg. slight mandibular retrognathia
MP-SN Angle	31.5 \pm 4.1	Degrees	Avg. high-angle (dolichofacial) tendency
Airway Variables			
Nasopharyngeal Volume (NPV)	7.5 \pm 1.8	^3	
Oropharyngeal Volume (OPV)	4.2 \pm 1.5	^3	
Minimum Cross-Sectional Area (MCA)	112.5 \pm 35.2	^2	

Correlation Between Skeletal Morphology and Airway Dimensions
Pearson's correlation analysis was performed to investigate the linear relationship between the skeletal morphology variables and the three airway dimensions (Table 2).

Table 2: Pearson's Correlation Coefficients (r) between Skeletal Variables and Airway Dimensions

Skeletal Variable	NPV (r)	OPV (r)	MCA (r)
ANB Angle	0.18	-0.65^	-0.71^
SNB Angle	0.05	0.59^	0.68^
MP-SN Angle	-0.25	0.48^	-0.53^
S-Go/N-Me Ratio	0.15	0.35^	0.31

$< 0.05; p < 0.01; p < 0.001

Key Correlation Findings:
- The **ANB angle** (maxilla-mandible discrepancy) showed a **strong negative correlation** with both **Oropharyngeal Volume (OPV)** and the **Minimum Cross-Sectional Area (MCA)**. This indicates that as the mandible becomes more retrognathic relative to the maxilla, the oropharyngeal space and the narrowest point of the airway significantly decrease.
- The **SNB angle** (mandibular position) showed a **strong positive correlation** with OPV and MCA. A more anteriorly positioned mandible is associated with larger airway dimensions.
- The **MP-SN Angle** (vertical growth pattern) showed a moderate negative correlation with OPV and MCA, suggesting that a **high-angle (long face) tendency** is associated with a more constrained oropharyngeal airway.
- No significant correlations were found between the measured skeletal variables and the Nasopharyngeal Volume (NPV).

Comparison of Airway Dimensions Across ENT Groups
One-way ANOVA was used to compare the mean airway dimensions across the three defined clinical groups (Table 3). Significant differences were found for both OPV and MCA.

Table 3: Mean Airway Dimensions by Clinical ENT Group

Airway Dimension	No Issues (n=16) Mean (cm3/mm2)	Hypertrophy (n=15) Mean (cm3/mm2)	OSA (n=15) Mean (cm3/mm2)	p-value (ANOVA)
NPV {cm}^3	8.0 \pm 1.2	6.8 \pm 1.9	7.6 \pm 1.8	0.09 (N.S.)
OPV	5.5 \pm 1.0	4.3 \pm 1.2	2.9 \pm 0.8	p < 0.001
MCA ^2)	145.1 \pm 25.5	110.3 \pm 31.8	80.2 \pm 20.1	p < 0.001

Post-Hoc Analysis (Tukey's HSD):

- **OPV:** The **OSA Group** had significantly lower mean Oropharyngeal Volume compared to both the **No Issues Group** ($p < 0.001$) and the **Hypertrophy Group** $p < 0.05$. The difference between the No Issues and Hypertrophy groups was also statistically significant ($p < 0.05$).
- **MCA:** The **OSA Group** demonstrated a significantly smaller Minimum Cross-Sectional Area compared to the **No Issues Group** ($p < 0.001$) and the **Hypertrophy Group** ($p < 0.05$).
- **NPV:** No significant differences were found in the Nasopharyngeal Volume across the three groups, which aligns with the fact that nasopharyngeal obstruction is typically dominated by soft tissue (adenoids), not skeletal factors.

Regression Analysis for Airway Prediction

Multiple Linear Regression was performed to determine which skeletal variables were the strongest independent predictors of the clinically critical **Minimum Cross-Sectional Area (MCA)**. Variables showing significant correlations (ANB angle, SNB angle, MP-SN angle) were included in the model, along with age.

Table 4: Multiple Linear Regression Model Predicting MCA {^2)

Predictor Variable	**Standardized Beta(β)**	**p-value**
ANB Angle	-0.51	0.003
SNB Angle	0.20	0.15
MP-SN Angle	-0.32	0.04
Age (years)	0.08	0.45

The model accounted for 62\% of the variance in MCA (Adjusted } R^2 = 0.62, p < 0.001.

Key Regression Findings:

- The **ANB angle** emerged as the **most powerful independent predictor** of reduced MCA beta = -0.51).
- The **MP-SN Angle** was also identified as a significant negative predictor beta = -0.32.
- These findings strongly suggest that the horizontal position of the mandible (Class II skeletal pattern) and the vertical dimension of the face (high-angle) are the dominant skeletal determinants of airway narrowing in this pediatric cohort.

Discussion

Overview of Principal Findings: This study utilized 3D volumetric CBCT analysis to investigate the complex interplay between maxillofacial skeletal morphology and upper airway dimensions in a pediatric cohort with and without documented ENT disorders. Our principal findings confirm a statistically and clinically significant relationship: specific skeletal patterns indicative of mandibular retrognathia and vertical facial growth are powerful determinants of reduced oropharyngeal airway volume and minimum cross-sectional area (MCA). Furthermore, the Obstructive Sleep Apnea (OSA) group exhibited the most severe airway restriction, validating the critical role of skeletal architecture in the pathophysiology of pediatric sleep-disordered breathing.

Interpretation of Skeletal-Airway Correlations: The strongest correlation observed was the negative association between the ANB angle (skeletal Class II tendency) and both OPV and MCA. This finding strongly supports the hypothesis that a posteriorly positioned mandible fundamentally constrains the tongue and soft palate, thereby reducing the available space in the oropharynx—the anatomical region most susceptible to collapse during sleep. The high negative correlation ($r = -0.71$) between ANB angle and MCA is particularly compelling, as MCA represents the functional "choke point" of the airway. Our Multiple Linear Regression analysis further solidified this finding, identifying the ANB angle as the most significant independent predictor of MCA (Table 4). This confirms that the skeletal base is not merely an associated factor, but a dominant predictor of airway patency. The moderate negative correlation of the MP-SN Angle (vertical pattern) with airway dimensions also supports existing literature suggesting that high-angle (dolichofacial) growth patterns are detrimental to airway integrity. In these cases, the hyoid bone and tongue are often positioned lower and more posteriorly, contributing to airway narrowing even in the absence of severe anteroposterior discrepancy. Notably, no significant correlations were observed between skeletal measurements and the Nasopharyngeal Volume (NPV). This is anatomically intuitive, as the NPV is primarily determined by the size of the adenoids, whose hypertrophy is the most common cause of nasopharyngeal obstruction in children, outweighing the relatively minor impact of the skeletal base in this region. This highlights the differential impact of skeletal versus soft-tissue factors along the airway tract.

Clinical Relevance: Airway Dimensions Across ENT Groups

The comparative analysis provided crucial clinical data (Table 3). While the Hypertrophy group showed a moderate reduction in OPV and MCA compared to the Control group, the OSA group demonstrated a profoundly lower mean OPV (2.9 \pm 0.8 ^3) and MCA (80.2 \pm 20.1 ^2). The fact that the OSA group's airway dimensions were significantly smaller than *both* other groups—including the soft-tissue-obstructed Hypertrophy group—underscores that pediatric OSA patients often suffer from a dual pathology: a pre-existing or co-existing skeletal constraint that magnifies the severity of soft-tissue obstruction. For children who undergo adenotonsillectomy (the primary surgical treatment for pediatric OSA), residual OSA is often attributed to non-lymphoid factors. Our data strongly suggest that the underlying maxillofacial skeletal morphology is a key factor contributing to this persistent or residual airway compromise, particularly in patients presenting with a significant Class II malocclusion.

Implications for Interdisciplinary Management (Dental and ENT)

The evidence generated by this study mandates a shift toward proactive, interdisciplinary assessment and treatment.

1. **Dental/Orthodontic Role:** Orthodontists and pediatric dentists are uniquely positioned to identify these skeletal risk factors early through routine clinical and radiographic examination. Patients presenting with a developing Class II skeletal pattern should be screened for breathing disorders. Early maxillary expansion and functional appliance therapy aimed at anteriorly repositioning the mandible are not merely cosmetic treatments but should be considered functional interventions with the potential to increase OPV and MCA, thereby mitigating future ENT-related morbidity.
2. **ENT Role**: Otolaryngologists must recognize that surgical removal of adenoids and tonsils may only address the soft-tissue component of obstruction. For patients with co-existing severe skeletal retrognathia, the ENT diagnosis should trigger a timely referral to an orthodontic or oral surgery specialist for concurrent or sequential management of the skeletal component, ensuring a more stable and complete resolution of the airway issue.

Limitations and Future Directions

Despite the rigorous 3D methodology, this study has limitations. As a cross-sectional study, it demonstrates association, not causation. We cannot definitively state whether the skeletal pattern caused the breathing disorder or if a long-standing, primary obstruction (e.g., adenoids) altered the skeletal growth trajectory. Future prospective, longitudinal studies utilizing skeletal tracking markers are necessary to fully elucidate this complex causal sequence. Furthermore, while CBCT provides anatomical data, it does not assess dynamic airway function or collapse during sleep. Future research should integrate 3D volumetric findings with objective measures of respiratory function, such as drug-induced sleep endoscopy (DISE) or manometry, to fully validate the clinical utility of the MCA measurement. In conclusion, this study provides strong, quantitative evidence bridging the anatomical gap between maxillofacial morphology and airway function in children. The identification of mandibular retrognathia as a key risk factor for airway compromise serves as a powerful call for integrated care protocols between Dental and ENT departments.

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