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Multimodal Assessment of Tongue Morphology and Airway Dimensions as Predictors of Obstructive Sleep Apnea Severity: An Orthodontic Perspective

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Abstract

Objective:

To evaluate the relationship between cephalometric, ultrasonographic, and acoustic pharyngometric airway parameters and obstructive sleep apnea (OSA) severity, and to identify independent anatomical predictors of Apnea–Hypopnea Index (AHI) from an orthodontic diagnostic perspective.

Materials and Methods:

This cross-sectional observational study included 42 adult patients (AHI > 5) referred for dental appliance therapy. Lateral cephalograms were used to measure tongue length (TGL) and tongue height (TGH). Submental ultrasonography assessed tongue thickness, tongue volume, and interlingual artery distance. Acoustic pharyngometry was performed to evaluate functional airway volume. Pearson correlation analysis assessed associations between anatomical variables and AHI. Multiple linear regression analysis identified independent predictors of AHI. Multicollinearity was evaluated using Variance Inflation Factor (VIF). Statistical significance was set at $p < 0.05$.

Results:

Interlingual artery distance ($r = 0.322$, $p = 0.038$) and tongue height ($r = 0.395$, $p = 0.010$) showed significant positive correlations with AHI, while acoustic pharyngometry demonstrated a significant negative correlation ($r = -0.424$, $p = 0.005$). Multiple linear regression analysis revealed that acoustic pharyngometry ($\beta = -0.524$, $p = 0.001$) and tongue volume ($\beta = -0.301$, $p = 0.040$) were significant independent predictors of AHI. The regression model explained 41.8% of the variance in AHI (adjusted $R^2 = 0.318$). No multicollinearity was detected (VIF range: 1.054–1.612).

Conclusions:

Functional airway volume assessed by acoustic pharyngometry emerged as the strongest independent predictor of OSA severity, followed by tongue volume. Linear cephalometric measurements alone were insufficient predictors when controlling for volumetric and functional variables. Integration of non-invasive airway evaluation methods into orthodontic diagnosis may enhance risk assessment and individualized treatment planning for patients with OSA.

Clinical Trial Registration

Not applicable (observational study)

INTRODUCTION

Obstructive sleep apnea (OSA) is a chronic sleep-related breathing disorder characterized by recurrent episodes of partial or complete upper airway obstruction during sleep, leading to intermittent hypoxia and sleep fragmentation.[1] The Apnea–Hypopnea Index (AHI) is the standard parameter used to quantify OSA severity; however, it reflects only the frequency of respiratory events and does not adequately explain the underlying anatomical mechanisms responsible for airway collapse.[2] Upper airway patency is governed by a complex interplay between craniofacial structure, soft-tissue morphology, and neuromuscular control.[10]

Among the soft-tissue components, the tongue plays a pivotal role as it constitutes the largest anatomical structure within the upper airway and directly influences retroglossal airway dimensions.[3] Variations in tongue morphology, including increased volume, vertical height, or posterior displacement, may contribute to airway narrowing and increase susceptibility to obstruction during sleep.[3,4] Previous studies utilizing magnetic resonance imaging and ultrasonography have demonstrated a significant association between increased tongue volume and the severity of obstructive sleep apnea.[3,6] Although advanced imaging modalities such as computed tomography and magnetic resonance imaging provide detailed anatomical insights, their routine clinical application is limited due to high cost, limited accessibility, and radiation exposure.[5] In contrast, submental ultrasonography offers a reliable, non-invasive, and radiation-free method for assessing tongue morphology, including thickness, transverse dimensions, and volumetric characteristics.[5,6]

In orthodontic practice, lateral cephalometry remains a fundamental diagnostic tool for evaluating craniofacial relationships and soft-tissue structures affecting airway dimensions.[11] Cephalometric parameters such as tongue length and tongue height provide valuable information regarding sagittal and vertical tongue position, both of which may influence airway patency.[2,11] In addition to structural evaluation, functional airway assessment techniques such as acoustic pharyngometry enable real-time measurement of airway volume and cross-sectional area, facilitating identification of airway narrowing and assessment of airway collapsibility.[9]

However, despite the availability of both structural and functional assessment methods, the relative predictive value of functional airway assessment compared to structural anatomical parameters remains unclear.[2,10] Identification of the most significant anatomical predictors of AHI is essential for improving diagnostic accuracy and guiding individualized orthodontic and dentofacial orthopedic treatment planning.[9,10]

Therefore, the present study aimed to evaluate the relationship between multimodal anatomical parameters—including cephalometric, ultrasonographic, and acoustic pharyngometric measurements—and obstructive sleep apnea severity, and to identify independent anatomical predictors of AHI.

MATERIALS AND METHODS

Study Design and Ethical Approval

This cross-sectional observational study was conducted to evaluate the association between anatomical airway parameters and obstructive sleep apnea severity. Ethical approval was obtained from the Institutional Ethics Committee (Ref: IEC/2025/770), and written informed consent was obtained from all participants prior to enrolment.

Sample Size Determination

Sample size estimation was performed prior to the study to ensure adequate statistical power for multiple linear regression analysis. Six independent anatomical predictor variables were included in the regression model: tongue thickness, interlingual artery distance, tongue volume, tongue length (TGL), tongue height (TGH), and acoustic pharyngometry measurements. Based on a large effect size (f^2 = 0.35), significance level of 0.05, and statistical power of 0.85, the minimum required sample size was calculated as 41 subjects. A total of 42 participants were included in the final analysis, ensuring sufficient statistical reliability (Table 2).

Table 2
Descriptive statistics of study variables (n = 42)

Variable	N	Minimum	Maximum	Mean	Standard deviation
Tongue thickness (mm)	**42**	**62 mm**	**73 mm**	**66.29**	**2.99**
Interlingual artery distance (mm)	**42**	**23.7 mm**	**39.9 mm**	**30.91**	**4.55**
Tongue volume (cm^3)	**42**	**60.17 cm^3**	**85.78 cm^3**	**77.05**	**6.75**
Tongue length (TGL) (mm)	**42**	**60.8 mm**	**68.0 mm**	**64.17**	**2.93**
Tongue height (TGH) (mm)	**42**	**38 mm**	**59 mm**	**49.76**	**5.66**
Apnea–Hypopnea Index (AHI)	**42**	**9.8**	**77.1**	**23.96**	**13.61**
Acoustic pharyngometry (cm^3)	**42**	**10.19 cm^3**	**43.17 cm^3**	**23.36**	**6.26**

Participants were recruited from adult patients referred for dental appliance therapy following a confirmed diagnosis of obstructive sleep apnea. Inclusion criteria comprised individuals aged 18 years or older, with an Apnea–Hypopnea Index greater than 5, adequate dentition to support dental appliance therapy, and the ability to undergo cephalometric, ultrasonographic, and acoustic pharyngometric evaluation. Exclusion criteria included individuals younger than 18 years, those with an Apnea–Hypopnea Index of 5 or less, patients presenting with craniofacial anomalies affecting airway anatomy, edentulous individuals or those with inadequate dentition, patients currently undergoing continuous positive airway pressure therapy, individuals taking psychiatric medications, and those with medical or anatomical conditions that could interfere with standardized measurements. After applying the inclusion and exclusion criteria, a total of 42 subjects were selected for final evaluation. A substantial proportion

of the study population demonstrated established anthropometric and skeletal risk factors associated with airway compromise. Most participants presented with elevated body mass index and increased neck circumference, both of which are associated with increased soft-tissue volume surrounding the pharyngeal airway and reduced airway patency. Adipose tissue deposition within the tongue, soft palate, and lateral pharyngeal walls may contribute to airway narrowing and increased airway collapsibility. In addition, craniofacial skeletal characteristics, including mandibular retrognathia and inferior hyoid bone position, may reduce posterior airway space by altering tongue posture and airway support. These variables were recorded as part of the study assessment; however, they were not included in the specific regression model evaluating craniofacial skeletal predictors. Future multivariate analyses incorporating anthropometric and skeletal variables may provide a more comprehensive understanding of airway obstruction.

Cephalometric Analysis

Standardized lateral cephalometric radiographs were obtained using the NewTom Giano imaging system with subjects positioned in natural head posture at end-expiration. Lateral cephalometry is a widely accepted orthodontic diagnostic tool for assessing craniofacial morphology and airway-related soft-tissue structures.[11] Manual tracing was performed to measure tongue length and tongue height. Tongue length (TGL) was defined as the linear distance between the tongue tip and the base of the epiglottis. Tongue height (TGH) was measured as the perpendicular distance from the highest point on the tongue dorsum to a reference point on the tongue length line. These measurements provide assessment of sagittal and vertical tongue morphology relevant to airway patency.[11]

Data Acquisition

1. Lateral Cephalometry

Imaging was performed using the NewTom Giano (G-XR-46893) system. To maintain consistency, images were captured at end-expiration with the patient in the Natural Head Position (NHP). Hard copies (8×10 inches) were manually traced to evaluate two specific parameters: tongue height (TGH) and tongue length (TGL). Identification of various landmarks used in the study was done as per the definitions illustrated in Fig. 1.

Eb (Base of the Epiglottis): This is the most postero-inferior point on the epiglottis. In the sagittal view, it is located anterior to the pf4 (posterior pharyngeal wall) landmark, specifically at the level of the lower pharynx.

TT (Tongue Tip): The most anterior point of the tongue.

TGL (Tongue Length): Defined as the linear distance connecting the TT point to the Eb point.

TH (Tongue Height): The highest point on the dorsal surface of the tongue.

Z (Reference Point): A point located on the TGL (TT–Eb) line. TGH is measured as the perpendicular distance from TH to this point Z.

Tongue Height (TGH): Evaluates the vertical bulk of the tongue within the oral cavity. It is used to identify if superior tongue displacement or increased height is encroaching upon the velopharyngeal space, which can increase airway resistance during sleep.

Tongue Length (TGL): Assesses the sagittal (anteroposterior) dimension of the tongue. A higher value often indicates a larger tongue mass that may be displaced posteriorly (macroglossia), potentially leading to narrowing of the oropharyngeal and hypopharyngeal airway. The lateral cephalometric analysis included evaluation of two tongue-related anatomical parameters: tongue height (TGH) and tongue length (TGL). Tongue height was defined as the perpendicular distance from point TH, representing the highest point on the dorsal surface of the tongue, to point Z located on the TT–Eb reference line. This measurement reflects the vertical dimension of the tongue and its potential influence on airway space. Tongue length was defined as the linear distance between point TT (tongue tip) and point Eb (base of the epiglottis), representing the anteroposterior dimension of the tongue and its relationship to the oropharyngeal airway. These parameters provide quantitative assessment of tongue morphology and its potential contribution to airway obstruction.[11] The anatomical landmarks and measurement definitions used in this study are illustrated in Fig. 2, and the corresponding cephalometric parameters and their diagnostic relevance are summarized in Table 1.

Table 1
Cephalometric parameters, definitions, and diagnostic relevance

S. No.	Cephalometric parameter	Description	Diagnostic value
1	**Tongue Height (TGH)**	**Distance from point TH (highest point on tongue dorsum) to point Z on the TT–Eb line, measured perpendicularly**	**Represents vertical tongue dimension influencing airway patency**
2	**Tongue Length (TGL)**	**Distance between point TT (tongue tip) and point Eb (base of epiglottis)**	**Represents anteroposterior tongue dimension influencing airway space**

Ultrasonographic Assessment

Submental ultrasonography was performed using a curvilinear transducer to evaluate tongue morphology. Ultrasonography provides a reliable, non-invasive, and radiation-free method for assessing tongue dimensions and airway-related soft tissues.[12,13] Tongue thickness was measured as the maximum vertical distance between the muscular plane of the floor of the mouth and the superior surface of the tongue. Tongue volume was calculated using anteroposterior and transverse dimensions obtained during ultrasonographic examination. Interlingual artery distance was measured using Doppler ultrasonography with a high-frequency linear transducer. The lingual arteries were identified using colour

Doppler imaging, and the transverse distance between the arteries was recorded as a measure of transverse tongue dimension (Fig. 3).[13]

Acoustic Pharyngometry

Acoustic pharyngometry was used to evaluate functional airway dimensions, including airway volume and cross-sectional area. This technique provides objective measurement of airway narrowing and has been validated as a reliable method for airway assessment in obstructive sleep apnea patients.[14] Measurements were obtained under standardized conditions with subjects in an upright position to ensure consistency and reproducibility (Fig. 4).

Statistical Analysis

All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) software (version 26.0, IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated for all variables and expressed as mean and standard deviation. Normality of data distribution was assessed using the Shapiro–Wilk test. Variables with $p > 0.05$ were considered normally distributed, while variables with $p < 0.05$ were considered non-normally distributed. Despite deviation from normality in certain variables, parametric tests were used, as regression analysis is robust to violations of normality when the sample size exceeds 30. Pearson correlation analysis was performed to evaluate the association between anatomical variables and Apnea–Hypopnea Index (AHI). Multiple linear regression analysis was conducted to identify independent predictors of AHI. The regression model included tongue thickness, interlingual distance, tongue volume, tongue length (TGL), tongue height (TGH), and acoustic pharyngometry as independent variables, and AHI as the dependent variable. Model fitness was assessed using the coefficient of determination (R^2), adjusted R^2, and ANOVA (F-test). Regression coefficients (B), standardized coefficients (β), and p values were evaluated to determine statistical significance. Multicollinearity was assessed using Variance Inflation Factor (VIF) and tolerance values. A p value < 0.05 was considered statistically significant.

RESULTS

A total of 42 subjects were included in the study. Descriptive statistics of the study variables are presented in Table 2. The mean Apnea–Hypopnea Index (AHI) was 23.96 ± 13.62, indicating moderate variability in obstructive sleep apnea severity among participants. The mean tongue thickness was 66.29 ± 2.99 mm, interlingual distance was 30.91 ± 4.56 mm, tongue volume was 77.05 ± 6.76 cm^3, tongue length (TGL) was 64.17 ± 2.93 mm, tongue height (TGH) was 49.76 ± 5.66 mm, and acoustic pharyngometry was 23.37 ± 6.26 cm^3. These findings indicate variability in anatomical airway and tongue parameters within the study population. Normality of data distribution was assessed using the Shapiro–Wilk test. Tongue thickness ($p = 0.045$), interlingual distance ($p = 0.030$), tongue volume ($p < 0.001$), TGL ($p < 0.001$), and AHI ($p < 0.001$) showed statistically significant deviation from normal distribution. In

contrast, TGH (p = 0.262) and acoustic pharyngometry (p = 0.271) demonstrated normal distribution (Table 3).

Table 3
Tests of normality (Kolmogorov–Smirnov and Shapiro–Wilk)

Variable	Kolmogorov–Smirnov Statistic	df	p value	Shapiro–Wilk Statistic	df	p value
Tongue thickness	0.134	42	0.055	0.946	42	0.045
Interlingual artery distance	0.127	42	0.088	0.941	42	0.030
Tongue volume	0.175	42	0.002	0.866	42	0.000
Tongue length (TGL)	0.496	42	0.000	0.174	42	0.000
Tongue height (TGH)	0.084	42	0.200 *	0.967	42	0.262
Apnea–Hypopnea Index (AHI)	0.213	42	0.000	0.788	42	0.000
Acoustic pharyngometry	0.096	42	0.200 *	0.967	42	0.271
***Lower bound of true significance (Lilliefors correction)**						

Pearson correlation analysis was performed to evaluate the association between anatomical variables and AHI (Table 4). A statistically significant positive correlation was observed between interlingual distance and AHI (r = 0.322, p = 0.038), indicating that increased interlingual distance was associated with greater severity of obstructive sleep apnea. Tongue height (TGH) demonstrated a statistically significant moderate positive correlation with AHI (r = 0.395, p = 0.010), suggesting that increased tongue height contributes to increased airway obstruction. A statistically significant moderate negative correlation was observed between acoustic pharyngometry and AHI (r = − 0.424, p = 0.005), indicating that reduced airway volume is associated with increased severity of obstructive sleep apnea. No statistically significant correlations were observed between AHI and tongue thickness (r = 0.049, p = 0.760), tongue volume (r = − 0.187, p = 0.237), or TGL (r = − 0.012, p = 0.940).

Table 4
Pearson correlation analysis between anatomical variables and AHI

Variable	Correlation coefficient (r)	p value	Interpretation
Tongue thickness	**0.049**	**0.760**	**Not significant**
Interlingual artery distance	**0.322**	**0.038 ***	**Significant positive correlation**
Tongue volume	**−0.187**	**0.237**	**Not significant**
Tongue length (TGL)	**−0.012**	**0.940**	**Not significant**
Tongue height (TGH)	**0.395**	**0.010 ****	**Significant positive correlation**
Acoustic pharyngometry	**−0.424**	**0.005 ****	**Significant negative correlation**
***p < 0.05; **p < 0.01**			

Multiple linear regression analysis was performed to identify independent predictors of AHI (Table 5). The overall regression model was statistically significant ($F = 4.185$, $p = 0.003$), indicating that the included predictors collectively explained variation in AHI. The model demonstrated an R value of 0.646, with an R^2 value of 0.418 and adjusted R^2 of 0.318, indicating that approximately 41.8% of the variance in AHI was explained by the predictor variables. Regression coefficient analysis revealed that acoustic pharyngometry and tongue volume were statistically significant independent predictors of AHI. Acoustic pharyngometry showed a statistically significant negative association with AHI ($B = -1.140$, $\beta = -0.524$, $p = 0.001$), indicating that reduced airway volume is associated with increased severity of obstructive sleep apnea. This variable demonstrated the strongest predictive effect among all predictors included in the model. Tongue volume also showed a statistically significant negative association with AHI ($B = -0.607$, $\beta = -0.301$, $p = 0.040$), indicating that tongue volume contributes significantly to airway obstruction and sleep apnea severity. Tongue thickness ($p = 0.235$), interlingual distance ($p = 0.146$), TGL ($p = 0.317$), and TGH ($p = 0.410$) were not statistically significant independent predictors of AHI after adjusting for other variables in the regression model.

Table 5
Regression coefficients (independent predictors)

Predictor	B	Standard error	Beta (β)	p value
Tongue thickness	**7.261**	**6.013**	**0.160**	**0.235**
Interlingual distance	**7.055**	**4.749**	**0.236**	**0.146**
Tongue volume	**−0.607**	**0.285**	**−0.301**	**0.040 ***
Tongue length (TGL)	**−0.204**	**0.201**	**−0.139**	**0.317**
Tongue height (TGH)	**3.287**	**3.940**	**0.137**	**0.410**
Acoustic pharyngometry	**−1.140**	**0.313**	**−0.524**	**0.001 ****
***p < 0.05; **p < 0.01**				

Multicollinearity was assessed using Variance Inflation Factor (VIF) and tolerance values (Table 6). VIF values ranged from 1.054 to 1.612, and tolerance values ranged from 0.620 to 0.949. These findings indicate absence of multicollinearity among predictor variables, confirming the stability and validity of the regression model. Acoustic pharyngometry was identified as the strongest independent predictor of AHI, followed by tongue volume. The regression model explained 41.8% of the variance in AHI, highlighting the significant role of airway dimensions and tongue morphology in determining the severity of obstructive sleep apnea.

Table 6
Multicollinearity diagnostics

Predictor	Tolerance	VIF	Interpretation
Tongue thickness	**0.949**	**1.054**	**No multicollinearity**
Interlingual artery distance	**0.658**	**1.519**	**No multicollinearity**
Tongue volume	**0.835**	**1.198**	**No multicollinearity**
Tongue length (TGL)	**0.882**	**1.134**	**No multicollinearity**
Tongue height (TGH)	**0.620**	**1.612**	**No multicollinearity**
Acoustic pharyngometry	**0.803**	**1.245**	**No multicollinearity**

DISCUSSION

Obstructive sleep apnea is a multifactorial condition influenced by both craniofacial morphology and soft-tissue characteristics of the upper airway. Although the Apnea–Hypopnea Index is the standard clinical parameter used to quantify disease severity, it does not provide insight into the anatomical mechanisms underlying airway obstruction. Therefore, identification of specific anatomical predictors is

essential for improving diagnosis and guiding orthodontic and dentofacial orthopedic treatment planning.

The present study demonstrated that acoustic pharyngometry was the strongest independent predictor of Apnea–Hypopnea Index, followed by tongue volume. These findings suggest that functional airway volume plays a more critical role in determining obstructive sleep apnea severity than isolated linear anatomical measurements. This observation is consistent with previous studies reporting that reduced pharyngeal airway volume is strongly associated with increased airway collapsibility and severity of obstructive sleep apnea.[16,17] Acoustic pharyngometry provides functional assessment of airway dimensions, allowing identification of airway narrowing that may not be fully captured using static imaging modalities.

The present study also found that tongue volume was a significant independent predictor of Apnea–Hypopnea Index. Increased tongue volume may contribute to posterior displacement of the tongue during sleep, resulting in narrowing of the retroglossal airway and increased airflow resistance. This finding is consistent with previous ultrasonographic and magnetic resonance imaging studies that have demonstrated a significant association between increased tongue volume and obstructive sleep apnea severity.[18,19] Smiesko et al.[18] reported that increased tongue volume was strongly associated with severe obstructive sleep apnea, suggesting that tongue enlargement contributes to airway obstruction. Similarly, Molnár et al.[19] demonstrated that tongue volume plays a critical role in airway narrowing and represents an important anatomical risk factor in obstructive sleep apnea patients.

Correlation analysis in the present study demonstrated significant positive associations between tongue height and Apnea–Hypopnea Index. Increased tongue height reflects greater vertical tongue bulk within the oral cavity, which may reduce available airway space and increase the likelihood of airway collapse during sleep. These findings are consistent with previous cephalometric investigations demonstrating that vertical tongue dimensions contribute to airway narrowing and obstructive sleep apnea severity.[20,21] Terawatpothong et al.[20] reported that increased tongue height was significantly associated with airway narrowing in high-risk obstructive sleep apnea patients. Similarly, Malkoc et al.[21] demonstrated that tongue position and morphology significantly influence airway dimensions and airway patency.

Interlingual artery distance also demonstrated a significant positive correlation with Apnea–Hypopnea Index in the present study. Increased interlingual artery distance may reflect greater transverse tongue dimension and soft-tissue volume, contributing to airway narrowing. This finding is supported by previous ultrasonographic studies demonstrating that increased transverse tongue dimensions are associated with increased airway obstruction and obstructive sleep apnea severity.[22] However, interlingual artery distance did not remain a significant independent predictor in the regression model, suggesting that its effect may be mediated through overall tongue volume and airway dimensions rather than acting as an independent determinant. In contrast, tongue thickness and tongue length did not demonstrate significant independent predictive value in the regression analysis. Although these variables contribute to tongue morphology, their individual contribution to airway obstruction may be

less significant compared with overall tongue volume and airway volume. These findings are consistent with previous investigations reporting that volumetric and functional airway measurements are more reliable predictors of obstructive sleep apnea severity than isolated linear measurements.[17,19] However, some studies have reported conflicting results. For example, Yu et al.[22] reported that tongue thickness was associated with airway obstruction in obstructive sleep apnea patients. These differences may be attributed to variations in study population, measurement techniques, and sample size.

The regression model in the present study explained 41.8% of the variance in Apnea–Hypopnea Index, indicating that anatomical factors play a substantial role in determining obstructive sleep apnea severity. However, the remaining variance may be attributed to other factors, including neuromuscular control, fat deposition, body mass index, and craniofacial skeletal morphology, which were not evaluated in the present study.[23] Obstructive sleep apnea is a complex condition influenced by both anatomical and physiological factors, and comprehensive evaluation requires assessment of both structural and functional parameters. From an orthodontic perspective, the findings of the present study have important clinical implications. Identification of anatomical predictors such as airway volume and tongue volume may assist orthodontists in identifying patients at increased risk of obstructive sleep apnea and in selecting appropriate treatment modalities, including mandibular advancement devices and other orthodontic interventions. Previous studies have demonstrated that orthodontic treatment can improve airway dimensions and reduce obstructive sleep apnea severity by modifying craniofacial structure and tongue position.[6,24] Therefore, incorporation of airway evaluation into orthodontic diagnosis may improve treatment planning and patient outcomes. The absence of multicollinearity among predictor variables in the present study confirms the reliability of the regression model and supports the validity of the findings. These results emphasize the importance of functional airway assessment and volumetric tongue evaluation in understanding obstructive sleep apnea pathophysiology.

The present study demonstrated several strengths, including the use of a multimodal diagnostic approach integrating cephalometric, ultrasonographic, and acoustic pharyngometric assessments, which enabled comprehensive evaluation of both structural and functional airway parameters. The use of ultrasonography provided a non-invasive, radiation-free, and clinically feasible method for assessing tongue morphology, while acoustic pharyngometry offered objective measurement of functional airway volume, which was identified as the strongest independent predictor of obstructive sleep apnea severity. The application of multiple linear regression analysis further strengthened the findings by identifying independent predictors while controlling for confounding variables, and the absence of multicollinearity confirmed the reliability of the model. However, certain limitations must be considered. The relatively small sample size may limit the generalizability of the findings, and the cross-sectional design does not allow establishment of causal relationships.

CONCLUSION

The findings of this study have important clinical and social implications, particularly in orthodontic practice. Identification of airway volume and tongue volume as independent predictors of obstructive sleep apnea severity highlights the importance of incorporating airway assessment into routine orthodontic diagnosis and treatment planning. Early identification of anatomical risk factors may allow timely intervention using orthodontic appliances, such as mandibular advancement devices, thereby improving airway patency and patient outcomes. From a public health perspective, early detection and anatomical evaluation of obstructive sleep apnea may help reduce associated systemic complications, including cardiovascular disease, metabolic dysfunction, and impaired quality of life. Within the limitations of this study, acoustic pharyngometry emerged as the most significant independent predictor of disease severity, followed by tongue volume, emphasizing the importance of functional airway evaluation. These findings support the integration of non-invasive airway assessment techniques into orthodontic practice to improve diagnosis, risk assessment, and individualized treatment planning, while future longitudinal studies with larger sample sizes are needed to further validate these observations.

Declarations

Conflict of Interest

The authors declare that they have no competing interests.

Study Design and Ethical Approval

This cross-sectional observational study was conducted to evaluate the association between anatomical airway parameters and obstructive sleep apnea severity. Ethical approval was obtained from the Institutional Ethics Committee of Armed Forces Medical College (AFMC), Pune, India (Ref: IEC/2025/770), and the study was conducted in accordance with the Declaration of Helsinki and the ICMR National Ethical Guidelines (2019). Written informed consent was obtained from all participants prior to enrolment.

Author Contributions (CRediT taxonomy)

A.T.: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Supervision, Writing – review & editing.

T.K.: Conceptualization, Investigation.

A.B.: Data curation, Formal analysis, Writing – review & editing.

S.R.: Formal analysis, Writing – review & editing.

M.C.: Formal analysis.

B.S.W.: Writing – review & editing.

S.Y.: Investigation.

B.J.: Supervision.

All authors read and approved the final manuscript.

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Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conference Presentation

This work has not been presented, in whole or in part, at any scientific meeting.

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Figures

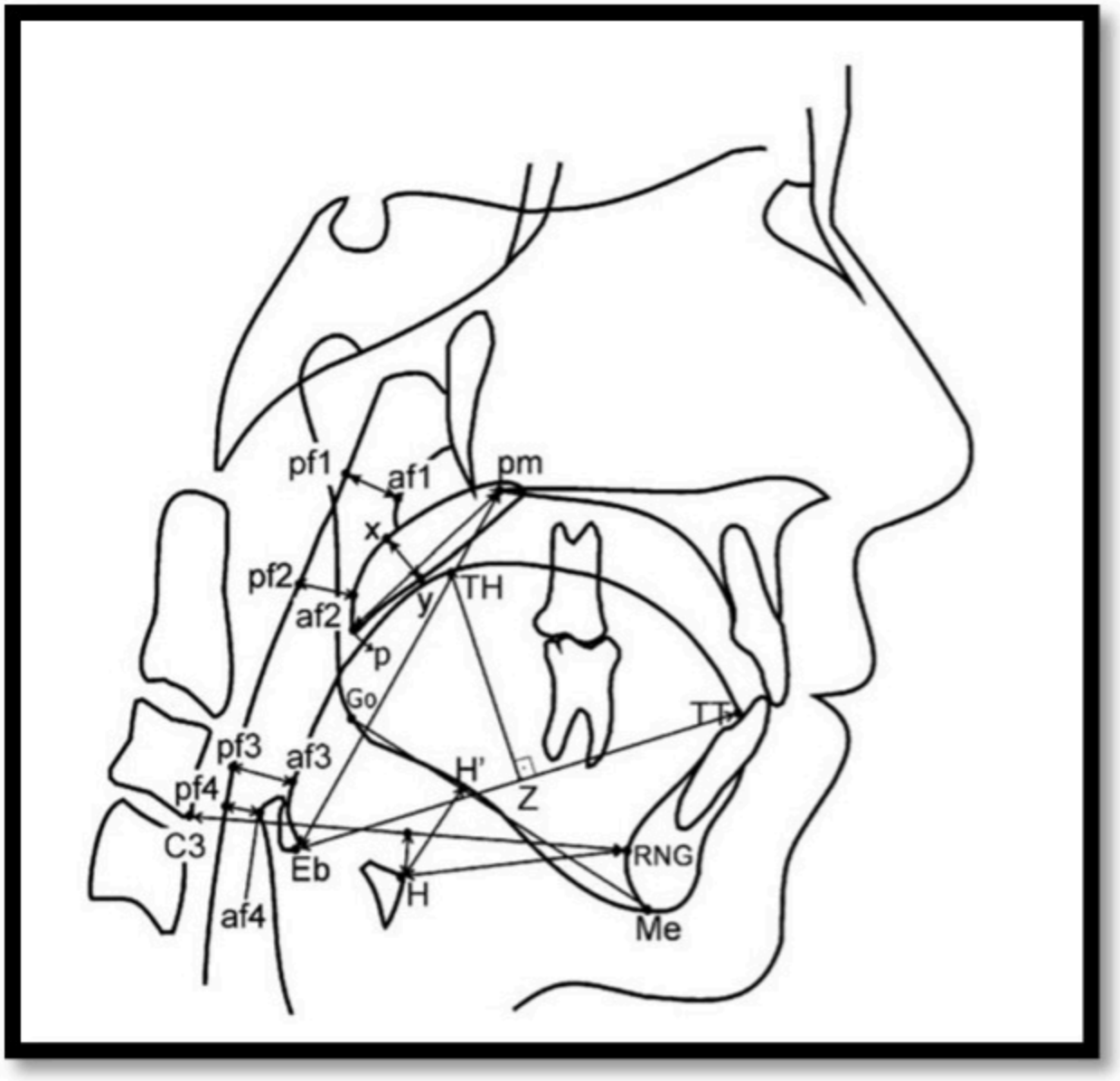


Figure 1

Lateral cephalometric tracing illustrating anatomical landmarks and reference lines used for measurement of tongue length (TGL) and tongue height (TGH). Tongue length was measured as the linear distance between the tongue tip (TT) and the base of the epiglottis (Eb), and tongue height was measured as the perpendicular distance from the highest point on the tongue dorsum (TH) to the TT–Eb reference line.

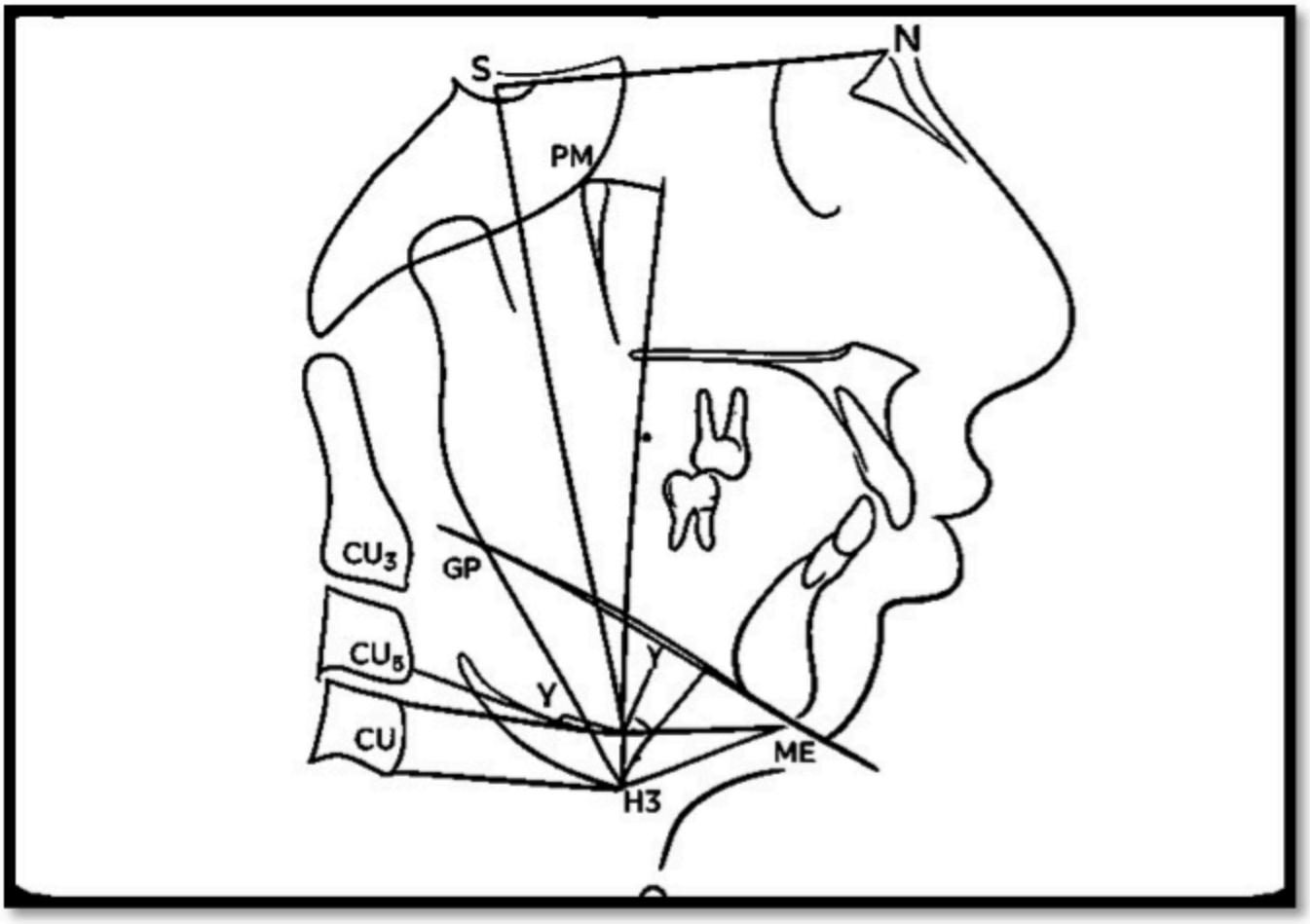


Figure 2

Diagram showing cephalometric reference planes and anatomical landmarks used for evaluation of tongue posture and craniofacial relationships influencing airway dimensions.

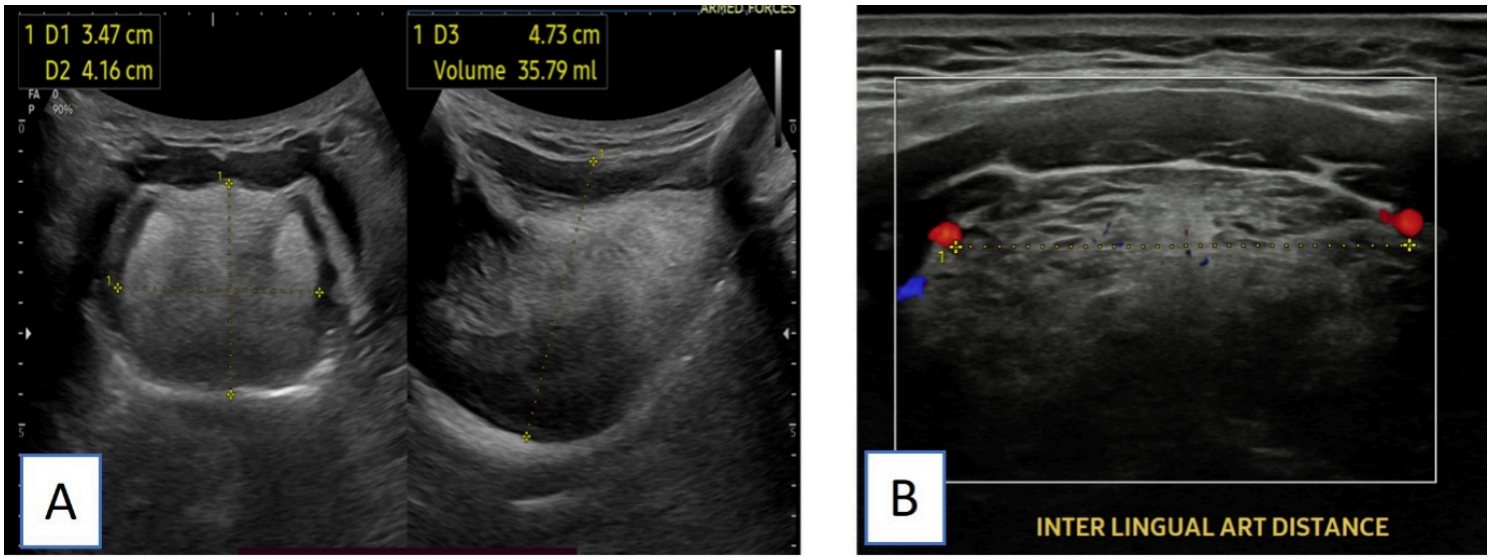


Figure 3

Ultrasonographic assessment of tongue morphology: (A) Submental sagittal ultrasonographic view demonstrating measurement of tongue thickness and volumetric parameters; (B) Transverse Doppler ultrasonographic view demonstrating measurement of interlingual artery distance.

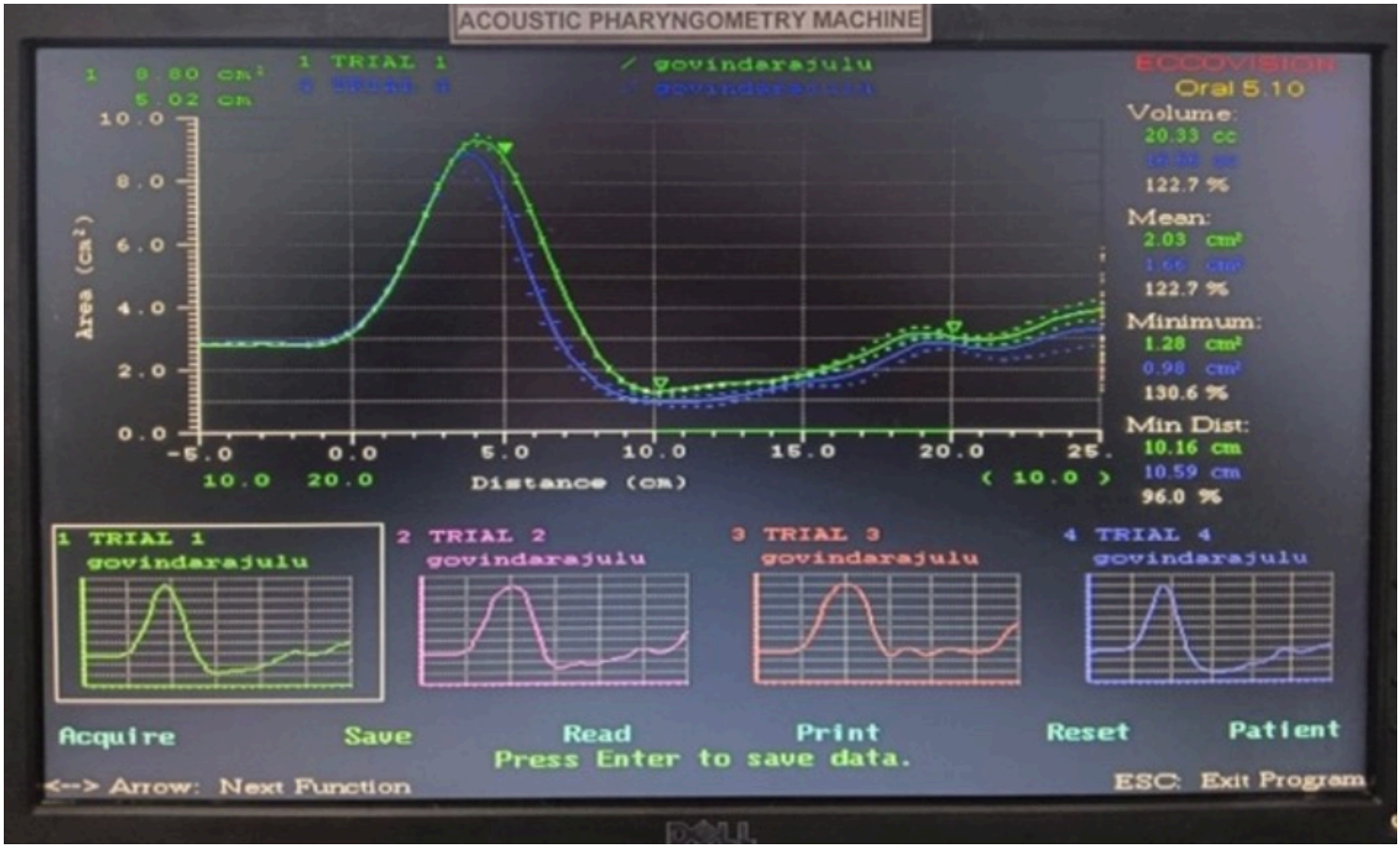


Figure 4

Acoustic pharyngometry tracing illustrating airway cross-sectional area and volume measurements used for functional assessment of upper airway dimensions.