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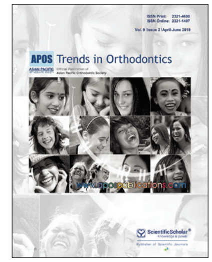

Original Article

An evaluation and correlation of airway space of pharynx, mandibular morphology, and tongue volume in skeletal classes and facial patterns – A cone beam computed tomography study

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ABSTRACT

Objectives: Respiration and its function have a direct relationship with the pharyngeal airway, mandibular morphology, and tongue. The objective of this study was to evaluate and correlate pharyngeal airway space, mandibular morphology, and tongue volume in various skeletal classes and facial patterns.

Material and Methods: A total of 120 pre-treatment cone beam computed tomography (CBCT) images were randomly classified into 3 skeletal classes (40/group). Each class was further categorized into hyperdivergent and hypodivergent growth patterns. Linear and angular measurements were estimated using three-dimensional digital imaging programs (Kavo 3D OnDemand software), and pharyngeal airway and tongue space were volumetrically analyzed by ITK-SNAP segmentation software.

Results: All the measured variables showed highly significant differences except for the anterior-posterior angle of the mandible, which was statistically insignificant with $P = 0.675$. The simple regression was formulated to assess the volume of airway space.

Conclusion: Hyperdivergent subjects had reduced pharyngeal airway space and tongue volume when compared to hypodivergent subjects. Among all the subgroups, Class III hypodivergent showed the highest pharyngeal airway volume and tongue volume, and the least was found in Class II hypodivergent. A direct relationship was estimated between airway mandibular morphology and tongue volume, recommending thorough analysis of oropharyngeal structures in a non-individualized way for orthodontic diagnosis and treatment planning.

Keywords: Airway, Cone beam computed tomography, Pharynx, Tongue

INTRODUCTION

The pharynx is a critical structure in the human respiratory system that not only has a significant role in deglutition and respiration but also has a crucial role in the growth and development of bones of craniofacial regions.[1,2] Any abnormalities in the soft tissue and craniofacial skeleton can change the pharyngeal airway system as a result of the posterior position of the mandible or maxillary retrognathism not only induces airway insufficiency and mouth breathing but also results in downward rotation of mandible, tongue, and extension of the head.[3,4] Furthermore, an extended head position and lowered tongue posture increase the mandibular load due to stretching of facial musculature, resulting in upright incisors and narrow arches, and predominantly, such features are seen in hyperdivergent growth patterns.[5,6]

According to "soft tissue stretching hypothesis"[7,8] stated that alterations in the normal naso-respiratory processes due to stretching of soft tissues oro-pharyngeal area have an extreme impact on the craniofacial development, especially during the period of active growth when a patient approaches for orthodontic treatment.[6,9,10]

Previous studies showed that growing individuals with Class II malocclusion had a constricted pharyngeal area, mainly of the oropharynx and hypopharynx, in comparison to Class I malocclusion.[1-3,10] Furthermore, skeletal movements during orthognathic surgeries do have an effect on the surrounding structures, such as maxillo-mandibular advancement procedures that result in movement of the posterior of the tongue, soft palate, hyoid bone, and frontal pharyngeal structures anteriorly. Similarly, any mandibular setback surgeries are also associated with the narrowing of the pharyngeal space.[11,12]

Recent advancements in the field of technologies and healthcare systems, like the use of cone-beam computed tomography (CBCT), have overtaken the previous 2-D methods or procedures. These CBCT multiplanar reconstructions (MPRs) and 3D evaluations provide data that are more accurate and reduce radiation dose.[13-15]

Considering the significance of determining the morphology of the pharyngeal airway in different facial skeletal patterns and its effect on treatment planning, this study was carried out to evaluate and correlate pharyngeal airway space, mandibular morphology, and tongue volume in individuals with various skeletal classes and facial patterns.

MATERIAL AND METHODS

Study design

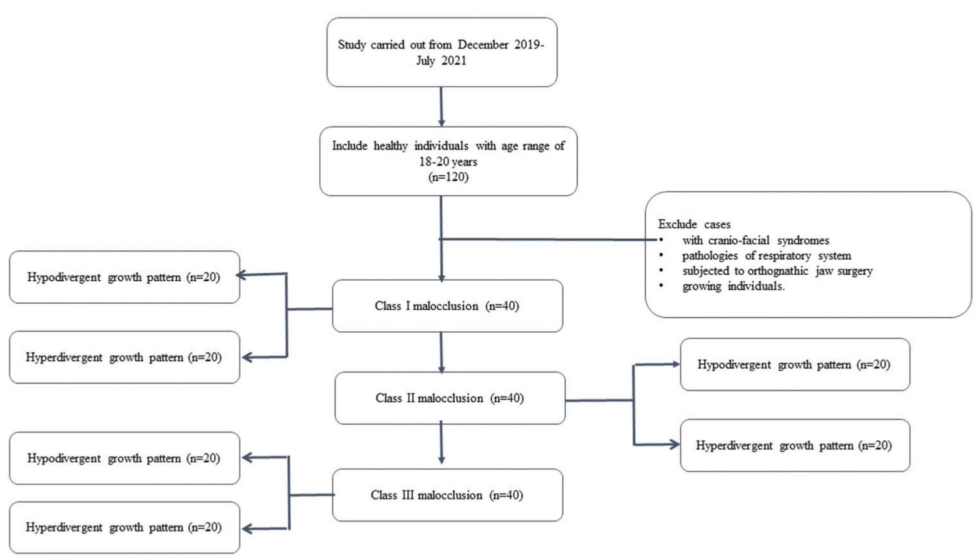
A study was performed on 120 patients whose CBCT images were recruited from the Department of Orthodontics and Dentofacial Orthopaedics. The Ethical Clearance Board, Al-Badar Rural Dental College, Kalaburagi, has approved this study, with certificate number (No. IEC/2019-20/03). The study was conducted from a period between December 2019 and July 2021. With a 95% confidence level and a margin of error of ±5%, a sample size of 120 subjects was allowed in the study. The power of sample size was analyzed by the formula $n = f(\alpha/2, \beta) \times 2 \times \sigma^2/(\mu_1 - \mu_2)^2$ where μ_1 and μ_2 are mean outcomes and σ is the standard deviation allowed in the study.

Inclusion criteria

The individuals were selected based on the inclusion criteria, i.e., healthy individuals in an age range of 18–20 years before orthodontic treatment or orthognathic surgery. The samples were classified into 3 skeletal classes: Class I, Class II, and Class III (40/group). Each class was further subdivided into two subgroups (20/subgroup) as hyperdivergent and hypodivergent, respectively as shown in Flowchart 1 below.

Exclusion criteria

1. Individuals of growing age or younger than 18 years
2. Individuals with craniofacial syndromes



Flowchart 1: Distribution of the samples.

3. Individuals subjected to orthognathic surgery and pathologies of the respiratory system like the history of enlarged adenoids or ear-throat infections and obstructive sleep apnea (OSA) (exclusion of OSA patients was on the history of the presence of at least one of the symptoms such as snoring, daytime sleepiness, choking, and nocturnal awakening and a diagnostic criterion as described by the International Classification of Sleep Disorders for OSA)[16]

Procedure

CBCT volumes were captured (Kavo 3D Pro imaging system, Palodex group OY, Finland) at 120 kV, 10mA, field of view of 13 × 15 cm, voxel size of 0.4 mm, and scanning time of 40 s. The CBCT images were acquired with every individual seated in the upright position and with the eye-ear plane parallel to the floor and the teeth of the patients in the maximal intercuspal position. The pre-treatment digital lateral cephalometric images were collected (CS IMAGING TECHNIQUE CS 8100 Rochester, NY USA). Digital Images (DICOM format) were exported to FACAD software (Version 3.10.1 Swedish Company, Ilexis AB Linkoping, SWEDEN) to classify into various classes and facial patterns.

The skeletal class was determined based on ANB, SNA, and SNB angle, while the facial pattern was differentiated as hypodivergent and hyperdivergent groups by calculating the VERT index of Rickets.[17]

The CBCT DICOM files were transferred to on-demand 3D software (version 1.0.10.746; CybeMed, Seoul, South Korea) for conversion to volumetric 3D MPR. For pharyngeal airway analysis, the reference line vertically was placed in the median sagittal plane, and the horizontal reference line was placed from the anterior nasal spine (ANS) to the posterior nasal spine (PNS) to reconstruct in axial and sagittal planes. Considering the mandible, the horizontal reference line was placed tangent to the lower border of the mandible for reconstruction in the sagittal plane and then extended to the genial tubercle in the superior direction [Figure 1a-d].[1]

The analysis of the pharyngeal space volume (PSV) was accomplished from a 3D model. From the reconstructed 3D model, PVS was measured in mm^3. PSV was evaluated by exporting the CBCT DICOM files to the ITK-SNAP software (version 3.8.0; Cognitica, Philadelphia, Pa; www.itksnap.org). From the MPR of images, the 3D models of the volume of the oropharynx and hypopharynx were reconstructed by utilizing the semi-automated segmented mode of the ITK-SNAP software.

The PSV in this research relates to the fusion between the oropharynx and the hypopharynx. Thus, we established the anatomic borderline according to Park *et al*.,[1,18] i.e., superiorly by taking a reference line at the right angle to midsagittal plane traced from the posterior-most point of the palatal plane (ANS-PNS) to the inferior most point of the C1 (first cervical vertebra) as CV1 plane and the anterior-inferior most point of the C2 (2nd cervical vertebra) as CV2 plane, similarly, CV3 plane and CV4 plane.[1] Based on these reference planes, the upper airway is divided into the oropharynx (between the CV1 and CV2 planes) and the hypopharynx (between the CV2 and CV4 planes) [Figure 1a]. Assessments of the anatomical parameters of the upper airway were measured as the largest transverse width, anteroposterior length, and cross-sectional area on the axial plane as shown in [Figures 1c, 2 and 3]. Parametres for measurement of mandibular morphology was shown in [Figure 4].

Boundaries to measure tongue volume were identified as the cementoenamel junction of posterior teeth (first molar and premolars) parallel to the X-axis plane both sagittally and axially, defining the ventral aspect of the tongue for segmentation. A plane at the right angle from the PNS in the axial orientation is defined to form the posterior aspect of the tongue for segmentation on the axial view. The occlusal plane was defined from the central cusps of the lower first molar to the incisal edge of the incisors for volume analysis, as shown in [Figure 5].

As the tongue is a soft tissue, for each patient, Hounsfield values (−650–200 HU) were set to calculate the maximum amount of voxel. According to the Hounsfield values chosen initially, the above-defined borders for the tongue were then added to form a three-dimensional mask of the volume of the tongue.

Volumetric analysis of the tongue was determined by utilizing the voxel volume from the scan and the number of voxels taken for a specific mask. To rule out inter-investigator

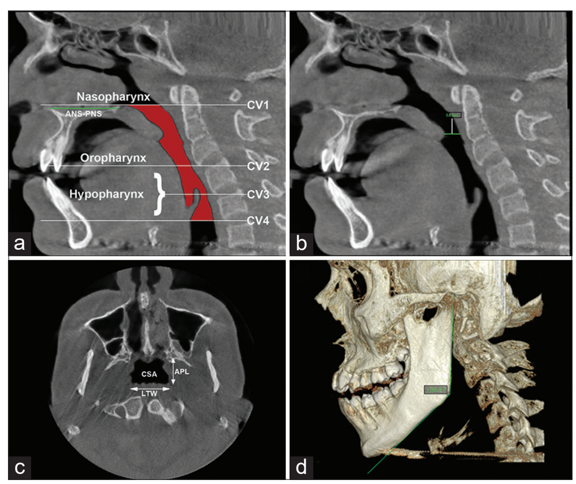


Figure 1: Parameters for pharyngeal airway analysis (a) Determine the reference planes sagitally, as the distance from anterior nasal spine to posterior nasal spine as CV1 plane. Cv1 to CV2 as Oropharynx and CV2 to Cv4 as Hypopharynx; (b) Constricted distance; (c) largest transverse width and anteroposterior length determines the anatomic characteristics of the upper airway and cross-section area on axial plane. Largest transverse width, anteroposterior length; (d) Gonial angle of mandible.

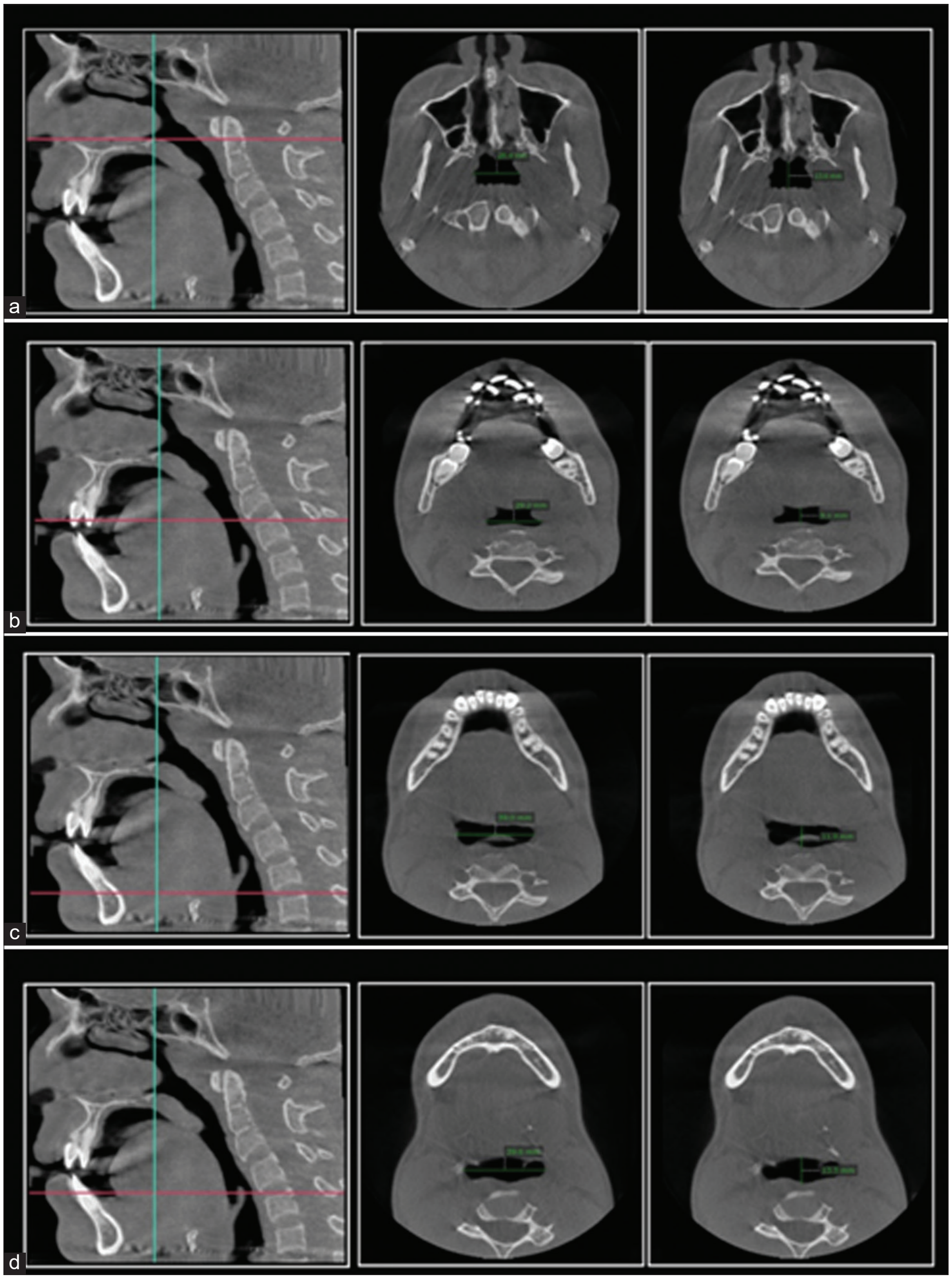


Figure 2: Parameters for pharyngeal airway analysis at the level of cervical vertebrae and epiglottis (a) interspace at C1, interspace at C1 anterioposteriorly, (b) interspace at C2 and interspace at C2 anterioposterioly, (c) interspace at C3 and Interspace at C3 anterioposteriorly, (d) Interspace at epiglottis and Interspace at epiglottis anterioposteriorly

variance, the same investigator determined all the parameters 2 times with a 1-week interval. To determine the reproducibility of the measured parameters, the intra-class correlation coefficient was calculated.[19]

The parameters analyzed are represented in [Tables 1 and 2].

Statistical analysis

The Statistical software IBM Statistical Package for the Social Sciences 20.0 (IBM Corporation, Armonk, NY, USA) was utilized for data analysis. Analysis of variance, unpaired

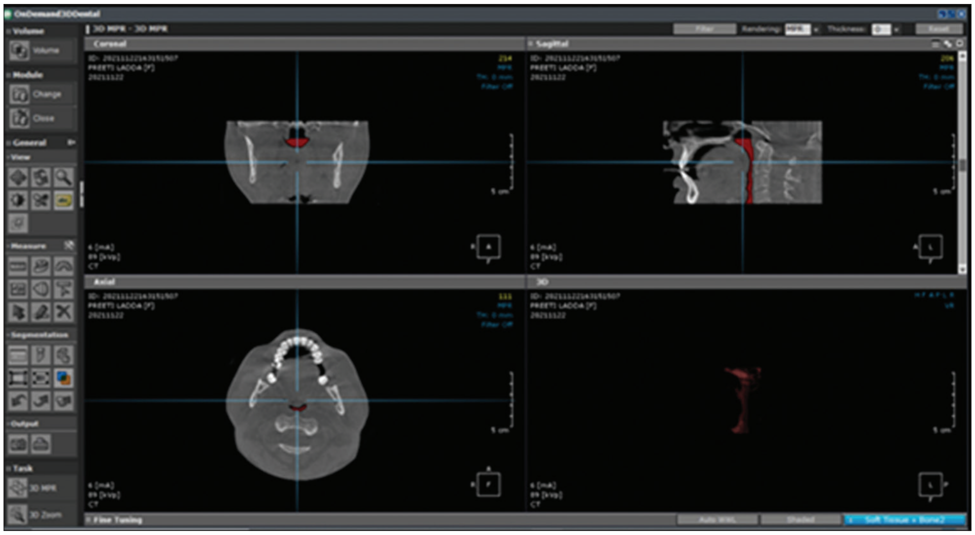


Figure 3: Segmentation of pharyngeal space described in the red text represents the 3D volume of union between the oropharynx and the hypopharynx.

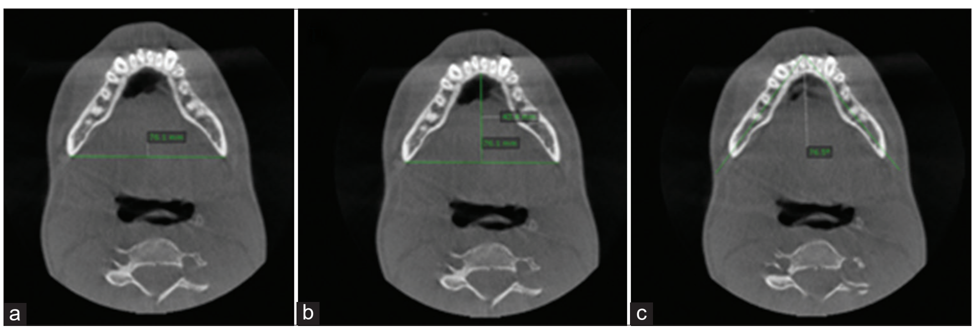


Figure 4: Parameters for mandibular morphology analysis (a) Inter-distance of mandible; (b) anterior-posterior distance of mandible; (c) Transverse angle of mandible.

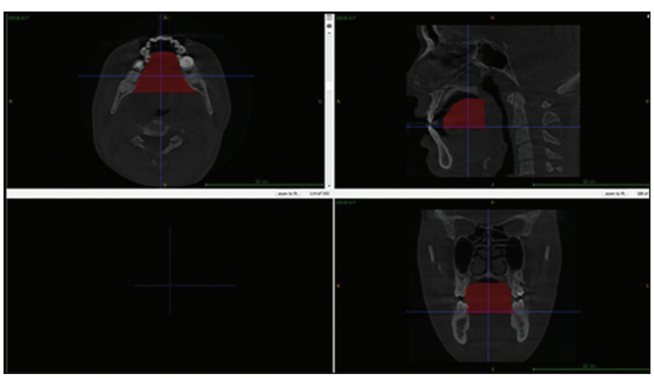


Figure 5: Segmentation of the tongue described in red text represents the 3D volume of tongue.

t-test, and Tukey test were used to evaluate and comparison of facial patterns and skeletal classes. Pearson correlation test was done to determine the correlations between the PSV and the other variables. The level of significance was kept at 0.05.

RESULTS

The intra-examiner intraclass correlation showed values between 0.76 and 0.97 for the angular measurements. The distribution of skeletal Classes is shown in [Table 3]. There were statistically significant differences in all the measured variables ($P < 0.001$) except for the gonial angle of the mandible, which showed statistically insignificant with $P = 0.675$.

The distribution of variables in different facial types, which showed highly significant differences ($P < 0.001$) while tongue volume showed a statistically significant difference at $P < 0.05$ whereas ANS-PNS, C1-LL distance, C1-AP distance, LL distance of mandible, and AP distance of mandible showed no statistically significant differences ($P < 0.05$) with $P = 0.223$, 0.067, 0.123, 0.475, and 0.37, respectively is showed in [Table 4].

As shown in [Table 5], a significant correlation was found between the PSV and the measured variables. In both facial types, the correlation between the parameter's airway volume

Table 1: Parameters for pharyngeal airway analysis.

Parameters	Definition of Parameters	Reconstructed plane
Pharyngeal space dimensions		
ANS to PNS distance [Figure 1a]	Linear distance from the anterior most to posterior most point on the palatal plane.	Sagittal
Constricted distance [Figure 2b]	Linear distance from the narrowest area of pharyngeal space horizontally	Sagittal
Intrerspace at C1 (lateral to lateral [LLC1]) [Figure 2a]	Linear distance horizontally from the greatest lateral to lateral measurement of pharyngeal space situated at the lowermost point at C1	Axial
Interspace at C1 anterio-posteriorly (APC1) [Figure 2a]	Linear distance vertically from the greatest measurement anterio-posteriorly of pharyngeal space situated at the lowermost point at C1	Axial
Interspace at C2 (lateral to lateral [LLC2]) [Figure 2b]	Linear distance in horizontal direction from the greatest lateral-lateral measurement of pharyngeal space situated at the lowermost point at C2	Axial
Interspace at C2 anterio-posteriorly (APC2) [Figure 2b]	Linear distance vertically from the greatest measurement anterio-posteriorly of pharyngeal space situated at the lowermost point at C2	Axial
Interspace at C3 (lateral to lateral [LLC3]) [Figure 2c]	Linear distance horizontally from the greatest lateral to lateral measurement of pharyngeal space situated at the lowermost point at C3	Axial
Interspace at C3 anterio-posteriorly [APC3] [Figure 2c]	Linear distance vertically from the greatest measurement anterio-posteriorly of pharyngeal space situated at the lowermost point at C3	Axial
Interspace at epiglottis (lateral to lateral [Epiglotiss-LL]) [Figure 2d]	Linear distance horizontally from the greatest lateral to lateral measurement of pharyngeal space situated at the point of maximum concavity of the stalk of the epiglottis.	Axial
Interspace at epiglottis-anterio-posteriorly (Epiglottis-AP) [Figure 2d]	Linear distance vertically from the greatest measurement anterio-posteriorly of pharyngeal space situated at the point of maximum concavity of stalk of the epiglottis.	Axial

ANS: Anterior nasal spine, PNS: Posterior nasal spine

Table 2: Parameters for mandibular morphology and tongue volume analysis.

Gonial angle [Figure 1d]	Angular measurement between the line from condylion to gonion and the line tangent to lower border of the mandible.	Sagittal
Inter-distance of mandible (LL) [Figure 4a]	Linear distance from the point of one gonion to the point of contra-lateral gonion.	Axial
Sagittal distance of mandible (AP) [Figure 4b]	Vertical line from the anterior most point on the lingual aspect of the mandibular symphysis to a line between both sides of the gonion points	Axial
Transverse mandibular angle. [Figure 4c]	Angular measurement between the anterior most point on the mental protuberance and the gonion point on both sides of the mandible.	Axial
Tongue volume (mm^3) [Figure 5]	Segmentation of the tongue on the ventral aspect: The cervical margin of mandibular posterior teeth will be rotated on the sagittal view in such a manner that the above plane will be parallel to the x-axis plane Segmentation of the tongue on the axial aspect: A right angle plane declining from the PNS in the axial direction will be considered to form the base of the tongue	

PNS: Posterior nasal spine

and ANS-PNS shows a negative correlation and is statistically significant for $P < 0.001$ for the hypodivergent pattern (−0.456).

In class III hypodivergent, the correlation between the airway volume and shortest distance (0.726, 0.585, respectively) shows a very good positive correlation and is significant with a $P < 0.001$.

Correlation between the airway volume and transverse angle of the mandible shows excellent negative correlation (−0.409, −0.771, −0.605, −0.706, −0.542, respectively) for class II and class III skeletal classes and both facial types and is statistically significant for $P < 0.001$.

Table 3: Comparison of different variables in terms of (Mean±[SD]) among skeletal classes using ANOVA test.

Variables	Class I (*n*=40)	Class II (*n*=40)	Class III (*n*=40)	*P*-value
ANS_PNS	46.250±2.0142	47.100±2.0295	44.835±1.8556	<0.001**
Constricted distance	6.485±1.6084	5.660±0.9432	7.315±1.3975	<0.001**
C1-LL	24.700±3.5141	20.090±3.6382	27.355±1.5457	<0.001**
C1-AP	8.995±3.0739	7.275±1.9390	10.925±2.1857	<0.001**
C2-LL	22.655±5.2095	19.420±3.5395	28.485±2.0807	<0.001**
C2-AP	7.065±1.9128	7.485±1.1360	9.940±1.9701	<0.001**
C3-LL	26.850±3.1011	23.740±1.5602	30.190±1.4293	<0.001**
C3-AP	9.130±1.9620	7.955±1.5377	10.370±1.5881	<0.001**
Epiglottis-LL	27.300±1.8453	24.765±1.2475	33.015±3.4038	<0.001**
Epiglottis-AP	10.195±1.3062	8.380±1.4162	11.545±1.5536	<0.001**
Airway volume	8119.6600±561.20097	5991.2075±1689.89360	11140.0700±1386.48827	<0.001**
Gonial angle	124.800±8.8729	125.650±8.5472	126.550±9.0155	0.675
Transverse mandibular angle	62.585±0.7701	63.010±0.9703	61.660±1.2868	<0.001**
Inter-distance of mandible	82.375±1.0655	83.455±0.3336	84.400±0.6854	<0.001**
AP-mandible distance	57.365±0.7866	58.000±0.4961	60.620±1.5119	<0.001**
Tongue volume	42962.235±926.5525	39251.695±1996.3261	50073.750±1609.6806	<0.001**

P<0.001 - Highly significant**. Same alphabets indicate significant difference using Tukey's *post hoc* analysis. ANS: Anterior nasal spine, PNS: Posterior nasal spine, ANOVA: Analysis of variance, SD: Standard deviation, CILL: Interspace at C1 lateral to lateral, C1AP: Interspace at C1 anterioposteriorly, C2LL: Interspace at C2 lateral to lateral, C2AP: Interspace at C2 anterioposteriorly, C3LL: Interspace at C3 lateral to lateral, C3AP: interspace at C3 anterioposteriorly.

Table 4: Comparison of different variables in terms of (Mean±[SD]) between both facial types using unpaired *t*-test.

Variables	Hypodivergent (*n*=60)	Hyperdivergent (*n*=60)	*P*-value
ANS_PNS	46.303±2.1762	45.820±2.1450	0.223
Constricted distance	7.323±1.4480	5.650±0.9986	<0.001**
C1-LL	24.763±5.1156	23.333±3.0994	0.067
C1-AP	9.467±3.0788	8.663±2.5696	0.123
C2-LL	25.317±4.4267	21.723±5.6159	<0.001**
C2-AP	8.780±2.3715	7.547±1.6461	<0.001**
C3-LL	27.933±3.2024	25.920±3.3330	<0.001**
C3-AP	10.053±1.8063	8.250±1.6840	<0.001**
Epiglottis-LL	29.973±4.6182	26.747±2.9208	<0.001**
Epiglottis-AP	10.760±1.9557	9.320±1.6094	<0.001**
Airway volume	9417.8640±2163.30421	7416.0943±2392.86501	<0.001**
Gonial angle	117.433±3.1642	133.900±2.6852	<0.001**
Transverse mandibular angle	61.710±0.9360	63.127±0.9264	<0.001**
Inter-distance of mandible	83.483±0.9603	83.337±1.2624	0.475
AP-mandible distance	58.800±1.9162	58.523±1.5520	0.387
Tongue volume (mm^3)	44969.263±4677.6871	43222.523±4742.3647	0.044*

P<0.05 - Significant*, *P*<0.001 - Highly significant**. ANS: Anterior nasal spine, PNS: Posterior nasal spine, SD: Standard deviation. C1-LL - Interspace at C1 lateral to lateral, C1-AP - Interspace at C1 anterioposteriorly, C2-LL- Interspace at C2 lateral to lateral, C2-AP- Interspace at C2 anterioposteriorly, C3-LL- Interspace at C3 lateral to lateral. C3-AP- Interspace at C3 anterioposteriorly.

The correlation between the parameters airway volume and tongue volume (0.921, 0.931, 0.984, and 0.964, respectively) shows an excellent positive correlation and is significant with a $P < 0.001$ for class II and class III skeletal pattern and in both facial types.

The results of the intergroup comparison of skeletal classes with hypodivergent growth pattern are shown in [Table 6], and all variables showed statistically significant differences ($P < 0.001$), the following variables showed significantly higher values for the shortest/constricted distance (8.420 ± 0.5307), C1-LL (28.130 ± 0.7935), C1-AP (10.960 ± 1.5581), C2-LL (27.980 ± 1.9509), C2-AP (10.960 ± 2.0423), C3-LL (30.450 ± 1.0566), C3-AP (11.080 ± 1.7392), epiglottis-LL (35.550 ± 3.0050), epiglottis-AP (12.390 ± 1.5), airway volume (12310.140 ± 858.6), gonial angle (118.0 ± 2.15), inter-distance of the mandible (84.320 ± 0.69), and tongue volume (51271.300 ± 1104.7) in Class III in comparison with class I and class II.

Table 5: Correlation between airway volume and all other variables, segmented in groups (facial types or skeletal classes).

Airway volume	Total	Class I	Class II	Class III	Hypo divergent	Hyper divergent
ANS-PNS						
Pearson correlation	−0.289**	−0.080	0.338*	0.103	−0.456**	−0.287*
Sig. (2-tailed)	0.001	0.622	0.033	0.528	0.000	0.026
n	120	40	40	40	60	60
Constricted t distance						
Pearson correlation	0.583**	0.248	0.382*	0.726**	0.585**	0.349**
Sig. (2-tailed)	0.000	0.123	0.015	0.000	0.000	0.006
n	120	40	40	40	60	60
C1-LL						
Pearson correlation	0.645**	0.214	0.093	0.474**	0.545**	0.852**
Sig. (2-tailed)	0.000	0.185	0.569	0.002	0.000	0.000
n	120	40	40	40	60	60
C1-AP						
Pearson correlation	0.526**	0.188	0.381*	0.039	0.405**	0.650**
Sig. (2-tailed)	0.000	0.245	0.015	0.811	0.001	0.000
n	120	40	40	40	60	60
C2-LL						
Pearson correlation	0.726**	0.579**	0.658**	−0.179	0.468**	0.843**
Sig. (2-tailed)	0.000	0.000	0.000	0.268	0.000	0.000
n	120	40	40	40	60	60
C2-AP						
Pearson correlation	0.557**	0.411**	0.009	0.560**	0.682**	0.299*
Sig. (2-tailed)	0.000	0.009	0.955	0.000	0.000	0.020
n	120	40	40	40	60	60
C3-LL						
Pearson correlation	0.764**	0.331*	0.618**	0.231	0.614**	0.845**
Sig. (2-tailed)	0.000	0.037	0.000	0.151	0.000	0.000
n	120	40	40	40	60	60
C3-AP						
Pearson Correlation	0.623**	0.584**	0.397*	0.545**	0.492**	0.587**
Sig. (2-tailed)	0.000	0.000	0.011	0.000	0.000	0.000
n	120	40	40	40	60	60
Epiglottis-LL						
Pearson correlation	0.897**	0.663**	0.471**	0.939**	0.959**	0.843**
Sig. (2-tailed)	0.000	0.000	0.002	0.000	0.000	0.000
n	120	40	40	40	60	60
Epiglottis-LL						
Pearson correlation	0.740**	0.449**	0.407**	0.556**	0.643**	0.764**
Sig. (2-tailed)	0.000	0.004	0.009	0.000	0.000	0.000
n	120	40	40	40	60	60
Gonial angle						
Pearson correlation	−0.356**	−0.560**	−0.912**	−0.839**	0.040	0.130
Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.762	0.322
n	120	40	40	40	60	60
Transverse angle of mandible						
Pearson correlation	−0.696**	−0.409**	−0.771**	−0.605**	−0.706**	−0.542**
Sig. (2-tailed)	0.000	0.009	0.000	0.000	0.000	0.000
n	120	40	40	40	60	60
Inter-distance of mandible						
Pearson correlation	0.351**	0.180	0.082	−0.157	0.519**	0.244
Sig. (2-tailed)	0.000	0.266	0.614	0.333	0.000	0.060
n	120	40	40	40	60	60
AP distance of mandible						
Pearson correlation	0.586**	0.070	−0.399*	0.250	0.781**	0.429**

(Contd...)

Table 5: *(Continued).*

Airway volume	Total	Class I	Class II	Class III	Hypo divergent	Hyper divergent
Sig. (2-tailed)	0.000	0.670	0.011	0.120	0.000	0.001
n	120	40	40	40	60	60
Tongue volume						
Pearson correlation	0.948**	0.027	0.921**	0.931**	0.984**	0.964**
Sig. (2-tailed)	0.000	0.869	0.000	0.000	0.000	0.000
n	120	40	40	40	60	60

Positive correlation means as one parameter value increases the other also increases. Negative correlation means as one parameter increases the other decreases. **Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed). ANS: Anterior nasal spine, PNS: Posterior nasal spine. C1-LL: Interspace at C1 lateral to lateral, C2-LL: Interspace at C2 Lateral to Lateral, C2-AP: Interspace at C2 anterioposteriorly, C3-LL: Interspace at C3 lateral to lateral, C3-AP: Intersapce at C3 anterioposteriorly

Table 6: The measured variables of hypodivergent skeletal pattern (Class I, Class II, Class III) using one-way ANOVA.

Variables	Class I		Class II		Class III		Intergroup comparison**
	Mean	SD	Mean	SD	Mean	SD	
ANS_PNS	46.000	2.4675	47.800	1.7205	45.110	1.3054	Class II>Class I>Class III
Constricted distance	7.400	1.6053	6.150	0.9649	8.420	0.5307	Class III>Class I>Class II
C1-LL	25.900	4.5229	20.260	5.0534	28.130	0.7935	Class III>Class I>Class II
C1-AP	9.690	3.8850	7.750	2.5320	10.960	1.5581	Class III>Class I>Class II
C2-LL	26.650	4.4595	21.320	3.317	27.980	1.9509	Class III>Class I>Class II
C2-AP	8.020	1.8266	7.360	1.4912	10.960	2.0423	Class III>Class I>Class II
C3-LL	28.610	3.4153	24.740	1.0870	30.450	1.0566	Class III>Class I>Class II
C3-AP	10.330	1.3479	8.750	1.5206	11.080	1.7392	Class III>Class I>Class II
Epiglottis-LL	28.930	0.6914	25.440	1.0976	35.550	3.0050	Class III>Class I>Class II
Epiglottis-AP	10.810	1.2736	9.080	1.4215	12.390	1.5697	Class III>Class I>Class II
Airway volume	8443.9700	98.21981	7499.4820	327.84472	12310.1400	858.68245	Class III>Class I>Class II
Gonial angle	116.700	4.4260	117.600	2.4366	118.000	2.1521	Class III>Class II>Class I
Transverse mandibular angle	62.030	0.4256	62.300	0.7211	60.800	0.8208	Class II>Class I>Class III
Inter-distance mandible	87.680	0.9243	83.450	0.3753	84.320	0.6971	Class I>Class III>Class II
AP-distance mandible	57.440	0.8586	57.820	0.6254	61.040	1.5198	Class III>Class II>Class I
Tongue volume	42674.700	1057.3285	40961.790	1163.5743	51271.300	1104.7493	Class III>Class I>Class II

(P<0.001 - Highly significant**). ANS: Anterior nasal spine, PNS: Posterior nasal spine, ANOVA: Analysis of variance, SD: Standard deviation, C1-LL: Interspace at C1 lateral to lateral, C1-AP: Interspace at C1 anterioposteriorly, C2-LL: Interspace at C2 lateral to lateral, C2-AP: Interspace at C2 anterioposteriorly, C3-LL: Interspace at C3 lateral to lateral, C3-AP: Interspace at C3 anterioposteriorly.

ANS-PNS (47.8 ± 1.7205) and transverse mandibular angle (62.300 ± 0.7211) showed significantly higher values in Class II compared to Class I and Class III in the hypodivergent growth pattern. Interdistance of the mandible (87.680 ± 0.92) showed significantly higher values for class I compared to class II and class III hypodivergent patterns.

As shown in [Table 7], comparison of skeletal classes with hyperdivergent growth pattern showed statistically higher values for shortest distance, C1-LL, C1-AP, C2-LL, C2-AP, C3-LL, C3-AP, epiglottis-LL, epiglottis-AP, airway volume, and tongue volume in class III compared to class I and class II. ANS-PNS, transverse mandibular angle, and AP mandibular distance showed significantly higher values in class II in comparison with class I and class III. AP-mandible distance showed significantly higher values for class I in comparison with class III and class II.

The simple linear regression equation resulted in the formula

PSV = 67.362 + (23.5 × LLC2) - (14.2 × constricted distance) - (21 × APC3) + (65.4 × inter-distance of mandible) - (38.8 × LLC1) + (20.8 × LL epiglottis) + (35.2 × APC1) + (9.391 × ANS-PNS distance) - (34.164 × LLC3).

The addition of further variables, namely age, sex, skeletal class, or facial pattern, did not refine the equation as shown in [Table 8].

DISCUSSION

The influence of respiration on the growth of craniofacial structure and its significance in treatment planning has been a controversial topic in the field of orthodontics.[2,7,20] Previous studies have stated that abnormal development

Table 7: The measured variables of hyperdivergent skeletal pattern (Class I, Class II, Class III) using one-way ANOVA.

Variables	Class I		Class II		Class III		Intergroup comparison**
	Mean	SD	Mean	SD	Mean	SD	
ANS_PNS	46.400	1.4517	46.500	2.1126	44.560	2.2814	Class II>Class I>Class III
Constricted distance	5.570	0.9852	5.170	0.6242	6.210	1.7355	Class III>Class I>Class II
C1-LL	23.500	1.3634	19.920	1.2539	26.580	1.7350	Class III>Class I>Class II
C1-AP	8.300	108122	6.800	0.9119	10.890	2.7198	Class III>Class I>Class II
C2-LL	18.660	1.4898	17.520	2.6667	28.990	2.1317	Class III>Class I>Class II
C2-AP	6.110	1.5012	7.610	0.6265	8.920	1.2672	Class III>Class II>Class I
C3-LL	25.090	1.2468	22.740	1.3076	29.930	1.7131	Class III>Class I>Class II
C3-AP	7.930	1.7472	7.160	1.1004	9.660	1.0445	Class III>Class I>Class II
Epiglottis-LL	25.670	0.9581	24.090	1.0151	30.480	1.1058	Class III>Class I>Class II
Epiglottis-AP	9.580	1.0411	7.680	1.0319	10.700	0.9937	Class III>Class I>Class II
Airway volume	7795.3500	644.51288	4482.9330	982.37185	9970.0000	571.22730	Class III>Class I>Class II
Gonial angle	132.900	1.9708	133.700	2.7549	135.100	2.8819	Class III>Class II>Class I
Transverse mandibular angle	63.140	0.6227	63.720	0.5926	62.520	1.0807	Class II>Class I>Class III
Inter-distance Mandible	82.707	1.1314	83.460	0.3500	84.480	0.6818	Class III>Class II>Class I
AP-distance Mandible	87.190	0.6843	58.180	0.2142	60.200	1.4179	Class I>Class III>Class II
Tongue volume	43249.770	685.6996	37541.600	818.4130	48876.200	1038.6684	Class III>Class I>Class II

(*P*<0.001 - Highly significant**). ANS: Anterior nasal spine, PNS: Posterior nasal spine, ANOVA: Analysis of variance, SD: Standard deviation

Table 8: The best (analysis of variance, F=187.195; *P*<0.0001) linear regression equation for airway volume.

Variables	Unstandardized coefficients		Standardized Coefficients	*t*	Sig.
	B	Std. Error	Beta		
(Constant)	67.362	5555.303		0.012	0.990
ANS_PNS	9.391	27.043	0.008	0.347	0.729
Constricted distance	−14.288	52.319	−0.009	−0.273	0.785
C1-LL	−38.892	19.113	−0.067	−2.035	0.044
C1-AP	35.269	26.046	0.041	1.354	0.179
C2-LL	23.518	15.765	0.051	1.492	0.139
C3-LL	−34.164	26.301	−0.047	−1.299	0.197
C3-AP	−21.003	53.789	−0.017	−0.390	0.697
Epiglottis-LL	20.898	33.177	0.035	0.630	0.530
Inter-distance of mandible	65.459	58.830	0.046	1.113	0.268

B: Unstandardized Coefficients, ANS: Anterior nasal spine, PNS: Posterior nasal spine

of the maxilla-mandibular structures can result in modification of the pharyngeal airway volume, which could lead to changes in soft and hard tissue structures like hyoid bone.[21-23]

Previous study has reported that pharyngeal tissues exhibit growth till the age of 13 years.[10] Most of the longitudinal studies have reported that the muscular palate increases in height and depth between 20 and 50 years. [10,24] Many investigators have utilized lateral cephalometric analysis to evaluate the pharyngeal airway space, identifying the definite hard and soft-tissue landmarks. A major disadvantage is that it lacks accurate description and characteristics of pharyngeal airway space. In this study, we used 3D CBCT imaging technology, which helped us to understand and visualize the 3D airway volume in a better way.[25]

Previous studies have reported adaptations in the PSV, such as extended or forwarded head posture, skeletal classes, and facial patterns[26-28], while few authors have assessed the pharyngeal volume in different skeletal classes, although the consequence was questionable.[6,14,29] Kormaz *et al*.[30] reported no significant difference in cranio-cervical angulation among obese and non-obese subjects without OSA, which might probably influence the head posture, according to body mass index (BMI). From this, we can conclude that there is no significant effect of BMI on the pharyngeal airway.

According to Jayaratne and Zwahlen,[31] there was a significantly larger oropharyngeal volumes in skeletal class III subjects in comparison with skeletal class II subjects, which was in concordance with our research. We consider that these differences among the studies might be due to discrete methodologies, which include variable sample sizes, ethnic groups, examination procedure (2-D or 3D technique), and use of different software programs.

A study by Chianchitlert *et al.*,[32] reported that subjects with retrognathic mandible exhibited a narrow pharyngeal airway space compared to individuals with normal sagittal skeletal pattern. While small and backwardly rotated mandible probably influences the tongue and the muscular palate in the posterior-inferior direction, which leads to encroach of the muscles of the pharynx in the gonial angle area with a resultant reduction in pharyngeal airway space.[25,33] Above findings were in agreement with our study, as class II hyperdivergent subjects showed a significant negative correlation between PSV and mandibular morphological parameters. Furthermore, a study by Syal *et al.*[10] stated that the position of the mandible in relationship with the cranial base has an influence on the oropharyngeal area.

Diwakar *et al.*[34] claimed that there was a direct relationship between the mandibular length and, the oropharyngeal airway and the total pharyngeal airway space. These discovered a relationship between mandibular length and airway size. The present study has exhibited that class III subjects showed higher pharyngeal volume and tongue volume, followed by class I and class II subjects. Since skeletal class III subjects showed more forwardly placed mandible and tongue, thereby increasing the linear dimension between posterior aspects of the tongue and the pharyngeal posterior wall, leading to enlarged pharyngeal volume and tongue volume in class III skeletal malocclusion than compared to skeletal class I and II malocclusion.[35] This was in agreement with studies by Kale and Buyukcavus,[6] Laranjo and Pinho,[36] and Habumugisha *et al.*[37] They reported that retrognathic class II subjects had reduced nasal pharyngeal and adenoidal tissue.

The current study shows a substantial correlation between the pharyngeal airway capacity and craniofacial characteristics, demonstrating the relationship between form and function. In relation to facial types, a highly significant difference was established in the hyperdivergent growth pattern and hypodivergent growth pattern. Among all the groups and subgroups, the Class III hypodivergent growth pattern showed larger pharyngeal volume and smaller pharyngeal volume was found in the Class II hyperdivergent growth pattern. According to a study done by Opdebeeck *et al.*,[38] the individuals with a long face have a narrower airway volume due to the reduced cross-section of the hyoid bone and backward positioning of the pharynx nearer to the cervical spine.

Another study by Kale and Buyukcavus[6] stated that subjects with hyperdivergent pattern with Class I and Class II malocclusion had a reduced oropharyngeal airway than subject with normodivergent pattern with Class I and Class II malocclusion. Previous studies have classified variable grades of OSA by assessing linear and angular measurements in the lower jaw, hyoid bone, and pharyngeal space, and they reported that the severity of OSA is more with smaller measurements.[29,39,40] In our research, we measured the pharyngeal space at the area of greatest constriction. The results exhibited that these measurements were lower in Class II hyperdivergent subjects.

Further, to enable the evaluation of PSV by experts without access to or knowledge of segmentation tools, a linear regression equation has been formulated using only linear measurements for the estimation of PVS. The above formula exhibited that our equation is probably helpful for airway volume assessment.

Therefore, we believe that our research has emphasized the significance of the inter-relation and compensation of morphological patterns of the mandible, tongue, and pharyngeal airway volume, and information regarding this will help in orthodontic diagnosis and treatment planning, especially for timely dentofacial orthopedic treatment interventions and need for referral to ENT specialist.

Future research scope

The present study excluded parameters such as body type or BMI to correlate with the growth pattern and pharyngeal airway volume. This research could be a foundational basis where further research should be conducted by considering the respiration phase, the BMI or neck circumference, and body types with respect to pharyngeal airway, tongue volume, and mandibular morphology.

CONCLUSION

- Within the scope of the study, it is stated that there is a direct relationship between pharyngeal space, mandibular morphology, and tongue volume.
- Among all the subgroups, Class III hypodivergent showed the highest pharyngeal airway volume and tongue volume, and the least was found in Class II hyperdivergent subjects, showing the influence on pharyngeal space, mandibular morphology, and tongue position.
- Thus, recommending thorough analysis of oropharyngeal structures in a non-individualized way for orthodontic diagnosis and treatment plan to obtain stable treatment outcomes.

Ethical approval

The research/study was approved by the Institutional Review Board at Al Badar Dental College and Hospital, number No. IEC/2019-20/03, dated 15/05/2019.

Declaration of patient consent

Patient's consent is not required as there are no patients in this study.

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Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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