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Relationship of Upper Pharyngeal Airway Volume and Tongue Position in Different Skeletal Patterns: A CBCT Study

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Abstract

Background and Aim: This study aimed to assess the relationship of upper pharyngeal airway volume with tongue position in different sagittal and vertical skeletal patterns using cone-beam computed tomography (CBCT).
Materials and Methods: CBCT images of 225 participants (149 females, 76 males) over 18 years of age were evaluated in three groups with sagittal class I, II, and III skeletal patterns. Class I and II individuals were subdivided into three vertical subgroups high angle, normal, and low angle. The CBCT scans were evaluated three-dimensionally, and the volume of the lower nasopharynx (LNP), oropharynx (ORP), and velopharynx (VLP) was calculated in addition to the total upper pharyngeal airway volume (TV). The tongue position (according to Graber's analysis and D1-D5 and D1'-D5' lines) was determined, and the tongue height (TGH) was measured. Data were analyzed by one-way and two-way ANOVA, Tukey's test, and Pearson's and Spearman's correlation tests (a=0.05).
Results: The volume of the LNP was significantly larger in class II than in class III patients ($P<0.05$). VLP volume ($r>0.5$, $P<0.05$) and TV ($r>0.5$, $P<0.05$) in class I high angle participants had a significant correlation with D1.
Conclusion: The present results showed greater LNP volume in class II than in class III individuals. In some variables (VLP, ORP, TV, intraoral airway volume) no significant difference was observed between different sagittal and vertical groups. Most of the airway variables (TV, VLP, ORP) had no correlations with some tongue variables (TGH, D1, D3, D4, D4', D5, intraoral airway volume) in different skeletal patterns.

Keywords: Skeletal Pattern; Upper Pharyngeal Airway Volume; Tongue Posture; Cone-Beam Computed Tomography

1. Background

The biological basis of orthodontics are mainly limited to the hard tissue structures such as bone and teeth. A review of the scientific orthodontic literature reveals that the current understanding of soft tissue forces and oral muscle balance has been poorly developed (1). Since the tongue plays an important role in the development of dental and skeletal malocclusions, its position should be considered in orthodontic and orthopedic treatment planning (2).

The relationship between craniofacial morphology and respiratory system function was noticed for the first time in the late nineteenth century (3). Evidence shows that a mutual correlation may exist between different facial growth patterns and the pharyngeal airway volume

(4-7). Airway obstruction can adversely affect and change the nasal respiratory function, resulting in craniofacial and tooth position anomalies (8,9). It has been reported that differences in oropharyngeal airway dimensions in individuals with different skeletal patterns may be due to their different tongue positions (10-12).

A previous two-dimensional study on the correlation between tongue position at rest and different skeletal patterns found no significant correlation in this regard (1). However, some other studies showed an average higher tongue position at rest in Class II individuals (13,14). Also, higher tongue position has been reported in individuals with a vertical growth pattern (15, 16). Nonetheless, another study reported lower tongue position at rest in individuals with vertical growth patterns (17).

Considering the existing controversy in the results of 2D studies on this relationship, cone-beam, computed tomography (CBCT) as a 3D imaging modality was recently used to address this relationship more accurately. Accordingly, some studies showed larger tongue volume in Class III (18) and lower tongue position in Class II individuals (19, 20). Another study indicated that anterior tongue position had a significant correlation with mandibular protrusion (20).

The majority of the available studies have indicated a lack of a significant correlation between the upper pharyngeal airway volume and different skeletal patterns (13, 20-25). Other studies demonstrated larger dimensions of the oropharynx in Class III individuals (23, 26), while another study showed significantly smaller nasopharyngeal volume in Class II patients (24). It was also reported that upper pharyngeal airway volume in individuals with a vertical growth pattern was narrower than that in individuals with a horizontal growth pattern (16, 17).

Studies addressing the correlation of tongue position at rest and airway volume in different skeletal patterns three-dimensionally are limited. Moreover, the sample size and mean age of participants in the available studies on this topic have been low, and mainly children during their growth period have been evaluated. Considering the existing controversy and the possible effect of tongue position on upper pharyngeal airway dimensions, this study aimed to assess the relationship between upper pharyngeal airway volume and tongue position in different sagittal and vertical skeletal patterns using CBCT.

2. Materials and Methods

This cross-sectional study was conducted on 225 CBCT scans taken between 2016 and 2021, that were retrieved from the archives of two oral and maxillofacial radiology centers. All participants had consented to using their imaging data for research purposes. The study protocol was approved by the Ethics Committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.DRC.REC.1400.036). All CBCT scans were obtained for diagnostic or treatment planning purposes unrelated to this study.

Sample size:

The sample size was calculated to be 30 in each group assuming α=0.05, β=0.2, study power of 80%, and effect size of 0.5. 225 CBCT scans were selected from the initial sample of 609 after applying the eligibility criteria.

Eligibility criteria:

The inclusion criteria were (I) age over 18 years, (II) complete eruption of permanent anterior teeth and second premolars, and presence of first and second molars in each quadrant, and (III) the tongue had to be at rest and not in full contact with the palate during CBCT scanning.

The exclusion criteria were (I) patients with a history of orthodontic or orthopedic treatment, (II) the presence of dental or craniofacial anomalies, and (III) syndromic patients and those with a history of trauma to the maxillofacial region.

Imaging protocol:

Imaging had been performed according to the standard protocol for all participants. During scanning, the patients were requested not to move, not to swallow their saliva, and to keep their tongue at rest. All CBCT scans were taken with exposure settings of 80 kV, maximum amperage of 2 mA, exposure time of 17 seconds, and a 0.39-mm voxel size.

Measurements:

For the measurements, the images (DICOM files) were reconstructed in the coronal, axial, sagittal, and 3D sections by OnDemand 3D software (CyberMed; File version: 1.0.10.6388; date created: 2017). A total of 229 axial slices with 0.78 mm slice thickness were assessed for each patient. The age and sex of patients, their skeletal measurements, length, height and position of their tongue, and upper pharyngeal airway volume were recorded for each patient.

Skeletal landmarks:

From the View menu, the Volume of Interest Overlay was selected. On the coronal view, the right half of the patient was omitted. Cephalometric landmarks and reference planes were then identified for the measurements as described in Table 1.

Table 1. Cephalometric landmarks and reference planes used for the measurements

Measurements	Description
ANS	The most anterior point on the sharp appendage of the maxilla in the lower part of the anterior nostril
EB	Base of epiglottis
Go	A point on the curvature of the angle of the mandible, which is formed by the bisector of the tangent lines on the lower edge of the mandible and the posterior edge of the ramus.
Gn	The point in the middle of the Pogonion point and the Menton point
Me	The lowest point in the symphysis of the mandible
N	The most anterior point at the intersection between the frontal and nasal bones in the midsagittal plane
PNS	The posterior spine of the palatine bone that forms part of the hard palate
Point A	The most posterior point in the concavity of the middle part of the face in the maxilla between the ANS and the prosthion
Point B	The most posterior point is in the middle part of the mandibular cavity, which is between the pogonion and the infradental
S	Sella turcica geometric center
TT	The most anterior point of the tongue
Ba	The lowest point on the anterior edge of the foramen magnum
So	Midpoint of the sella-basion line
Ad1	The intersection of the PNS- Ba line and the posterior wall of the nasopharyngeal airway
Ad2	The intersection of the PNS-So line and the posterior wall of the nasopharyngeal airway
T2	Intersection between tongue contour and occlusal plane
P3	The junction between the posterior pharyngeal wall and the occlusal plane
E	The uppermost point of the epiglottis
E1	The anterior wall of the pharyngeal airway is on the E1-E2 line, which is a line parallel to the occlusal plane
E2	The posterior wall of the pharyngeal airway is on the E1-E2 line
Functional occlusal plane	The line connecting the meeting place of the cusps of the first molar to the meeting place of the cusps of the first premolar

Skeletal analyses:

The participants were evaluated in three groups with sagittal Class I, II, and III skeletal patterns. Class I and Class II individuals were subdivided into three vertical subgroups of high angle, normal, and low angle. The following skeletal analyses were used for classifications (1):

The Jarabak ratio: posterior facial height/anterior facial height × 100, and values between 62-65% indicated normal, values >65% indicated low angle, and values <62% indicated high angle.

SN-MeGo: values between 28.5°-39.5° indicated normal, values >39.5° indicated high angle, and values <28.5° indicated low angle.

ANB: Class I: 0-4°, Class II: >4°, C lass III: <0°.

Tongue position analyses:

The following parameters were measured:

Tongue length (TGL): The distance between the base of the epiglottis (EB) and tongue tip (TT) was measured on the mid-sagittal section in the sagittal plane in X-ray mode and reported in millimeters (Fig. 1a).

Tongue height (TGH): The length of the vertical bisection from the dorsal surface of the tongue to the line connecting the base of the epiglottis and TT was measured on the mid-sagittal section in the sagittal plane in X-ray mode and reported in millimeters (Fig. 1a).

Tongue position (Graber analysis): A horizontal line was drawn from the incisal edge of the lower central incisor to the cervical third of the distal surface of the second molar on the mid-sagittal section in the 3D view. The selected point at the cervical third of the distal surface of the second molar was considered as the center point from which 30, 60, 90, 120, and 150-degree angles were drawn. The distances between the distal surface of the second molar and the tongue contour (D1-D5 lines) and from the tongue contour to the palate were measured at these points (D1’-D5’) (Fig. 1b).

Upper pharyngeal airway volume measurements:

Lower nasopharynx (LNP) volume: This part of the airway was confined to the Ad2-PNS line superiorly and the Ad1-PNS line inferiorly. Its volume was measured in the 3D view in airway mode (Fig. 2a).

Velopharynx (VLP) volume: This part of the airway was confined to the Ad1-PNS line superiorly and the T2-P3 line inferiorly. Its volume was measured in the 3D view in airway mode (Fig. 2a).

Oropharynx (ORP) volume: This part of the airway was confined to the T2-P3 line superiorly and the E1-E2 line inferiorly. Its volume was measured in the 3D view in airway mode (Fig. 2).

Total volume (TV) of the upper airways: This area was confined to the Ad2-PNS line superiorly and the E1-E2 line inferiorly. Its volume was measured in the 3D view in airway mode (Fig. 2a).

Intraoral airway volume: The intraoral airway volume was also measured as shown in Fig. 2b.

Reliability of measurements:

One trained and calibrated dental student made all the measurements on the anonymous CBCT images. The anatomical points and landmarks on 20 randomly selected images were remeasured by an orthodontist, and the inter-examiner reliability was calculated. Also, 20 CBCT scans were randomly selected and remeasured by the examiners after a 2-week interval to calculate intra-examiner reliability. The level of agreement was calculated using the intraclass correlation coefficient (ICC) and paired t-test.

Statistical analysis:

Data were analyzed using the software SPSS version 20 (SPSS Inc., IL, USA). Considering the normal distribution of data as confirmed by the Kolmogorov-Smirnov test (P>0.05) and homogeneity of variances as confirmed by the Levene’s test (P>0.05), one-way ANOVA was applied to compare upper pharyngeal airway variables among the three sagittal skeletal classes followed by the Tukey’s HSD test for pairwise comparisons. Two-way ANOVA was used to compare upper pharyngeal airway variables among patients with six different sagittal skeletal and vertical patterns. The correlation between the upper pharyngeal airway variables and tongue variables was analyzed by Pearson’s and Spearman’s correlation coefficients. The level of

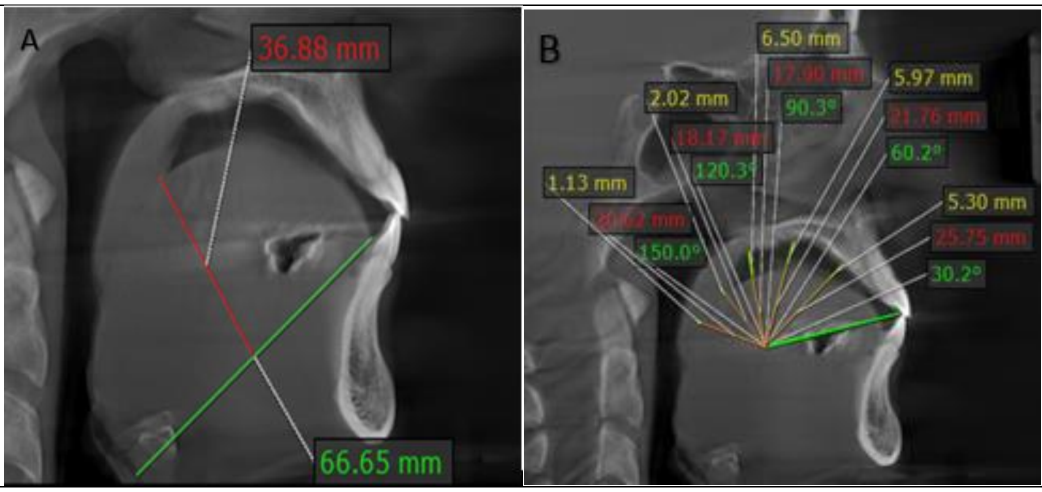

Figure 1. Measurements of the tongue dimensions and position: (a) TGL and TGH measurements; (b) assessment of tongue position on the 3D view in X-ray and R modes (red lines: D1-D5, yellow lines: D1'-D5').

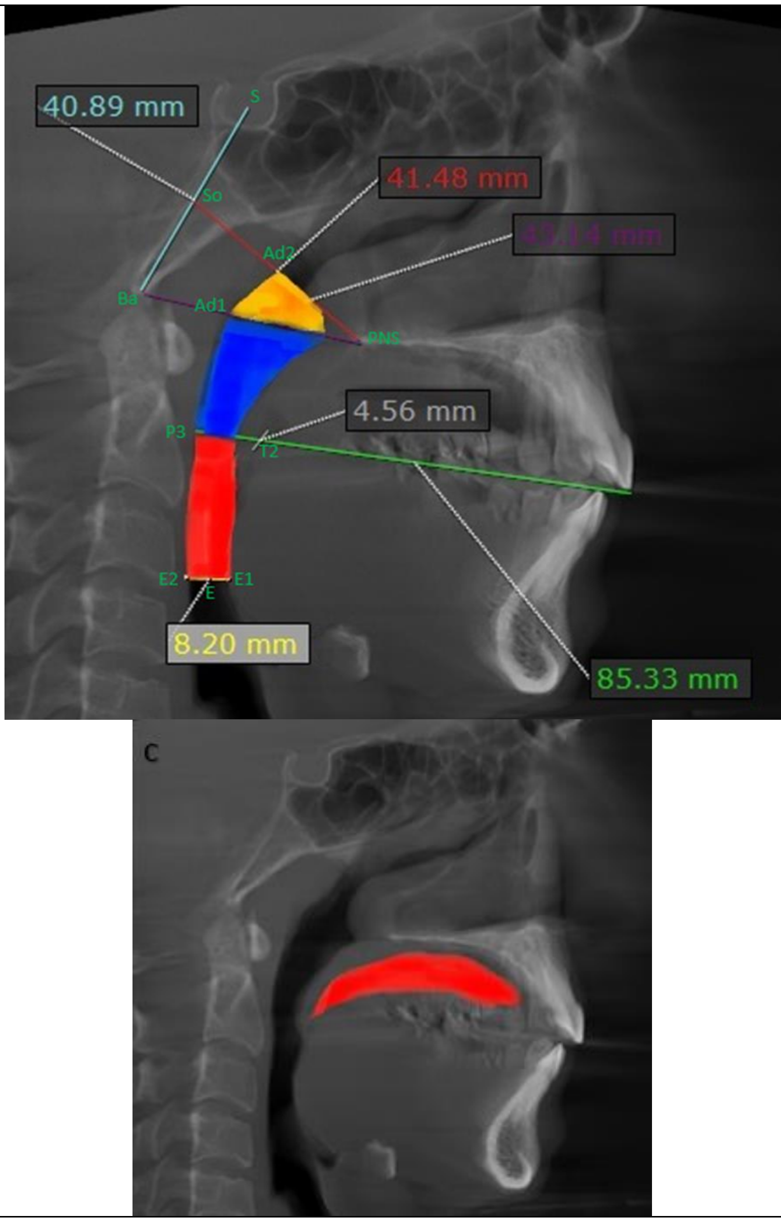

Figure 2. (a) Volume of the upper pharyngeal airway was measured in 3 parts using the anatomical landmarks: lower nasopharynx (LNP; yellow), velopharynx (VLP, blue), and oropharynx (ORP, red); (b) measurement of intraoral airway volume

3. Results

CBCT images of 149 females (66.12%) and 76 males (33.8%) were evaluated. The mean age of the participants was 33.06±10.77 years (range: 18-77 years). A total of 100 patients had Class I, 100 had Class II, and 25 had Class III skeletal patterns. Of 100 Class I patients, 37 were low angle, 33 were normal, and 30 were high. Of 100 Class II patients, 36 were low angle, 33 were normal, and 31 were high angle.

Results of reliability assessment:

The ICC value was found to be 1 (95% CI: 0.99-1) for intra-examiner reliability, and 0.998 (95% CI: 0.99-1) for inter-examiner reliability. The paired t-test showed a mean difference of 0.06±0.50 for intra-examiner reliability (P=0.400) and 0.01±0.85 for inter-examiner reliability (P=0.939), indicating no significant differences between the two measurements.

Results of airway measurements:

Table 2 presents the mean airway dimensions measured in the three sagittal skeletal classes. Significant differences were noted in Go-Gn (P=0.000) and LNP (P=0.046) among the three classes. Thus, pairwise comparisons were carried out (Table 3), which showed significantly higher LNP volume in Class II than in Class III individuals (P=0.045). Also, the Go-Gn length in Class III individuals was greater than that in Class I and Class III individuals(P=0.000 and P=0.001 respectively). Go-Gn length in Class I individuals was significantly greater than that in Class II patients (P=0.017).

Table 4 presents the measured airway dimensions in different sagittal and vertical skeletal patterns. Two-way ANOVA showed no significant difference in LNP, VLP, ORP, TV, and intraoral airway volume among the vertical and sagittal groups and their interactions (P>0.05).

Correlation of tongue position and airway dimensions in different sagittal skeletal patterns:

As shown in Table 5, VLP volume in Class II patients showed a low inverse correlation with TGH (r=-0.224, P=0.025). ORP volume in Class I individuals showed a low inverse correlation with D4 (r=-0.237, P=0.018) and D5 (r=-0.254, P=0.011). In the Class III group, ORP volume had a low correlation with D3 (r=0.404, P=0.045). TV in Class II patients had a low inverse correlation with TGH (r=-0.211, P=0.035).

Table 2. Mean airway dimensions measured in the three sagittal skeletal classes

Related variables	Sagittal skeletal pattern	Mean	Std. deviation	P value*
Go – Gn	Class I	73.64	4.76	0.000*
	Class II	71.64	5.24	
	Class III	77.93	6.12	
	Total	73.23	5.46	
LNP	Class I	3.82	1.39	0.046*
	Class II	3.82	1.44	
	Class III	3.04	1.53	
	Total	3.72	1.44	
VLP	Class I	5.25	2.48	0.927
	Class II	5.38	2.63	
	Class III	5.40	2.55	
	Total	5.33	2.54	
ORP	Class I	5.14	2.04	0.646
	Class II	5.41	2.58	
	Class III	5.50	2.07	
	Total	5.30	2.29	
TV	Class I	14.01	4.87	0.757
	Class II	14.48	5.57	
	Class III	13.81	4.86	
	Total	14.19	5.18	
Intraoral airway volume	Class I	1.28	2.11	0.466
	Class II	0.94	1.82	
	Class III	1.28	2.25	
	Total	1.13	2.00	

*One-way ANOVA

Table 3. Pairwise comparisons of skeletal classes regarding LNP and G-Gn length by Tukey's HSD test

Related variables	Sagittal skeletal pattern	Sagittal skeletal pattern	Mean difference	P value
LNP	Class I	Class II	-0.02527	0.991
		Class III	0.74579	0.054
	Class II	Class III	0.77106	0.045*
Go – Gn	Class I	Class II	2.00540	0.017*
		Class III	-4.28560	0.001*
	Class II	Class III	-6.29100	0.000*

Table 4. Measured airway dimensions in different sagittal and vertical skeletal patterns

Related variables	Sagittal skeletal patterns	Vertical skeletal patterns	Mean	Std. deviation
Go - Gn	Class I	High angle	73.50	5.04
		normal	73.87	4.59
		Low angle	73.40	4.79
	Class II	High angle	70.78	4.10
		Normal	71.25	4.68
		Low angle	72.74	6.43
LNP	Class I	High angle	3.48	1.24
		Normal	3.93	1.53
		Low angle	3.92	1.38
	Class II	High angle	4.09	1.61
		Normal	3.60	1.10
		Low angle	3.78	1.55
VLP	Class I	High angle	4.82	2.16
		Normal	4.46	2.61
		Low angle	5.43	2.61
	Class II	High angle	5.01	2.33
		Normal	5.52	2.79
		Low angle	5.58	2.75
ORP	Class I	High angle	5.02	1.90
		Normal	5.05	2.09
		Low angle	5.31	2.14
	Class II	High angle	5.23	2.17
		normal	5.27	2.76
		Low angle	5.67	2.78
TV	Class I	High angle	13.16	4.53
		normal	14.28	4.96
		Low angle	14.45	5.11
	Class II	High angle	14.21	4.92
		normal	14.27	5.50
		Low angle	14.89	6.24
Intraoral airway volume	Class I	High angle	1.50	2.07
		normal	0.95	2.03
		Low angle	1.39	2.23
	Class II	High angle	1.56	2.74
		normal	0.79	1.28
		Low angle	0.55	0.97

Table 5. Correlation of tongue position and airway dimensions in different sagittal skeletal patterns

Airway variables	Sagittal skeletal patterns		TGH	D3	D4	D5
LNP	Class I	Correlation Coefficient	-0.81	0.107	-0.033	-0.032
		P value	0.420	0.289	0.474	0.751
	Class II	Correlation Coefficient	-0.186	-0.125	-0.166	-0.160
		P value	0.065	0.216	0.099	0.112
	Class III	Correlation Coefficient	-0.317	-0.332	-0.272	-0.309
		P value	0.122	0.105	0.189	0.133
VLP	Class I	Correlation Coefficient	-0.076	0.062	-0.119	-0.115
		P value	0.452	0.539	0.239	0.253
	Class II	Correlation Coefficient	-0.224*	0.064	-0.095	-0.105
		P value	0.025*	0.527	0.347	0.297
	Class III	Correlation Coefficient	0.000	0.117	0.163	0.082
		P value	0.998	0.576	0.435	0.699
ORP	Class I	Correlation Coefficient	0.138	0.034	-0.237*	-0.254*
		P value	0.171	0.735	0.018*	0.011*
	Class II	Correlation Coefficient	-0.128	-0.006	-0.105	-0.065
		P value	0.203	0.954	0.299	0.522
	Class III	Correlation Coefficient	0.358	0.404*	0.255	0.106
		P value	0.079	0.045*	0.218	0.614
TV	Class I	Correlation Coefficient	-0.005	0.076	-0.175	-0.179
		P value	0.958	0.452	0.081	0.074
	Class II	Correlation Coefficient	-0.211*	-0.003	-0.133	-0.120
		P value	0.035*	0.976	0.185	0.234
	Class III	Correlation Coefficient	0.068	0.136	0.110	-0.010
		P value	0.748	0.516	0.599	0.961

Correlation of tongue position and airway variables with Go-Gn:

A small correlation was found between ORP volume and Go-Gn in Class I (r=0.299, P=0.002) and Class II (r=0.208, P=0.038) participants, but not in the Class III group.

Correlation of tongue position and airway variables in different sagittal and vertical skeletal patterns:

LNP volume: No significant correlations were noted in this regard.

VLP volume: In Class I high angle participants, a moderate correlation was found between VLP volume and D1 (r=0.514, P=0.004). In the Class I normal group, a low correlation was found between VLP volume and D4’ (r=0.441, P=0.008), and VLP volume and intraoral airway volume (r=0.441, P=0.010). In the Class II low angle group, a low inverse correlation was noted with D4’ (r=-0.385, P=0.020).

ORP volume: In the Class I high angle group, a small correlation was noted between ORP volume and D1 (r=0.472, P=0.004).

TV: In the Class I high angle group, a moderate correlation was found between TV and D1 (r=0.528, P=0.003). In the Class I normal group, a small correlation was found between TV and D4’ (r=0.463, P=0.007). In the Class II normal group, a small inverse correlation existed between TV and D5 (r=-0.357, P=0.042).

No other significant correlations were found (P>0.05).

Correlation of pharyngeal airway variables with Go-Gn in different sagittal and vertical skeletal patterns:

In the Class I high angle group, a small correlation was noted between Go-Gn and VLP volume (r=0.419, P=0.021), ORP volume (r=0.441, P=0.015), and TV (r=0.438, P=0.016). No other significant correlations were found (P>0.05).

4. Discussion

This study assessed the relationship of upper pharyngeal airway volume with tongue position in different sagittal and vertical skeletal patterns using CBCT. The results showed no significant difference in TV of the airways among different sagittal groups, which was in agreement with the findings of Di Carlo et al. (22) who assessed the correlation of upper airway volume with different craniofacial patterns (Class I, II, and III). This result was also in agreement with the findings of Alves et al. (25) who evaluated the upper airway volume in Class II and Class III patients using CBCT, and El and Palomo (26) who evaluated airway dimensions in patients with different sagittal positions of the maxilla and mandible.

In the present study, the LNP volume in Class II individuals was larger than that in the Class III group while the difference between Class I and Class II groups was not significant in this regard. This finding was different from the results of Di Carlo et al. (22) who found no significant difference in the volume of the nasopharynx among different groups. This difference in the results of the two studies may be because individuals over 18 years of age were included in the present study while the study population in the study by Di Carlo et al. (22) also included adolescents in their growth period (13 to 43 years). This difference in the results may indicate that the airway growth pattern may change with age, and growth and development can affect this pattern. The present results were also in contrast to the findings of El and Palomo (26) who showed smaller nasopharyngeal airway dimensions in skeletal Class II patients compared with the Class I group. The nasal volume in their study included the nasopharynx, conchae, and nares, while in the present study, the volume of the lower part of the nasopharynx was measured. This can explain the variations in the results. Larger LNP volume in Class II patients can be due to the forward position of the maxillary complex.

In the present study, the VLP volume was not significantly different in individuals with different skeletal patterns, which was in agreement with the results of Di Carlo et al. (22), and different from the findings of Claudino et al. (27), who showed smaller VLP volume in Class II than Class III and Class I groups. Their sample size was smaller than the present study, and they used the uvula as the lower extension of the VLP while the functional occlusal line was used as a reference for the lower extension of the VLP in the current study (16). Moreover, Iranian patients were assessed in the present study. These factors can explain the variations in the results.

In the present study, the ORP volume was not significantly different among different skeletal patterns, which was in line with the results of Alves et al. (25) and Memon et al. (28), and in contrast to the findings of El and Palomo (29). The latter study showed that the ORP volume was smaller in patients with a retruded mandible. This difference can be due to their small sample size. Nonetheless, a positive correlation was found between the mandibular length and ORP volume in Class I and Class II groups, which was in agreement with the results of Alves et al. (30) and El and Palomo (29).

In the present study, no significant difference existed in the upper pharyngeal airway volume in different vertical subgroups. This result was consistent with the findings of Grauer et al. (31), who assessed the form and volume of the upper pharyngeal airways and their correlation with facial morphology by CBCT. However, this result was in contrast to the findings of Tarkar et al. (16), de Freitas et al. (32), and Ucar and Uysal (17). They all showed that individuals with vertical growth patterns had narrower upper airway dimensions than those with horizontal growth patterns. This difference can be because previous studies assessed the airway dimensions two-dimensionally.

The intraoral airway volume was not significantly different in different skeletal patterns in the present study, which was consistent with the findings of Iwasaki et al. (20), who found no significant difference in the intraoral airway volume among Class I, II, and III groups.

In the present study, the VLP volume, ORP volume, and TV had low to moderate correlations with some variables related to the tongue position (TGH, D1, D3, D4, D4’, D5, and intraoral airway volume) in some skeletal groups. This finding was in agreement with the results of Battagel et al. (10), who showed that the hyoid bone and its muscular system play a key role in pharyngeal airway volume, and the position of the mandible and tongue affect the position of the hyoid bone. Thus, tongue position can affect the pharyngeal airway volume.

In the present study, an inverse correlation existed between VLP volume and TV with TGH, which can indicate the effect of increased TGH in reduction of airway volume and decreased respiratory function. By an increase in TGH, the hyoid bone with the attached tongue muscles (genioglossus and geniohyoid) is shifted backward. As a result, the VLP volume decreases, and thus, the TV of the airway reduces as well.

In the present study, a small correlation existed between the mandibular length and ORP volume in Class I and II groups, which was in agreement with the findings of Diwakar et al. (33) and Trenouth and Timms (34). One possible reason may be that by increased mandibular length, the genioglossus and geniohyoid muscle attachments are moved forward and farther from the muscles, increasing in ORP volume.

In the present study, the majority of variables related to the tongue position (TGL, D1’, D2, D2’, D3’, and D5’) had no significant correlation with airway variables. The reason may be that although patients were asked to keep their tongue at a resting position, the distance between the tongue and palate was very small in most cases and the oral volume was filled with the tongue almost completely.

Assessment of both the sagittal and vertical dimensions, larger sample size compared with previous investigations (18), and optimally high intra- and inter-examiner reliability were among the strengths of the present study.

This study had some limitations as well. The tongue position in most cases was such that the residual air volume was too small, and since the tongue position can easily change, the obtained results may not have sufficient reliability and reproducibility.

Future studies are required to find a reliable method for the assessment of tongue position on CBCT scans. Sagittal skeletal patterns can also be divided into smaller subgroups to determine which jaw is responsible for malocclusion, and the relationship of these subgroups should be assessed with the airway volume. Moreover, airway volume should be compared among individuals in different age groups.

5. Conclusion

The present results showed greater LNP volume in Class II than in Class III individuals. In some variables (VLP, ORP, TV, intraoral airway volume) no significant difference was observed between different sagittal and vertical groups. Most of the airway variables (TV, VLP, ORP) had no correlations with some tongue variables (TGH, D1, D3, D4, D4’, D5, intraoral airway volume) in different skeletal patterns.

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