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Position of the hyoid bone and its correlation with airway dimensions in different classes of skeletal malocclusion using cone-beam computed tomography

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ABSTRACT

Purpose: This study investigated the position of the hyoid bone and its relationship with airway dimensions in different skeletal malocclusion classes using cone-beam computed tomography (CBCT).
Materials and Methods: CBCT scans of 180 participants were categorized based on the A point-nasion-B point angle into class I, class II, and class III malocclusions. Eight linear and 2 angular hyoid parameters (H-C3, H-EB, H-PNS, H-Me, H-X, H-Y, H-[C3-Me], C3-Me, H-S-Ba, and H-N-S) were measured. A 3-dimensional airway model was designed to measure the minimum cross-sectional area, volume, and total and upper airway length. The mean cross-sectional area, morphology, and location of the airway were also evaluated. Data were analyzed using analysis of variance and the Pearson correlation test, with P values <0.05 indicating statistical significance.
Results: The mean airway volume differed significantly among the malocclusion classes ($P<0.05$). The smallest and largest volumes were noted in class II (2107.8 ± 844.7 mm^3) and class III (2826.6 ± 2505.3 mm^3), respectively. The means of most hyoid parameters (C3-Me, C3-H, H-Eb, H-Me, H-S-Ba, H-N-S, and H-PNS) differed significantly among the malocclusion classes. In all classes, H-Eb was correlated with the minimum cross-sectional area and airway morphology, and H-PNS was correlated with total airway length. A significant correlation was also noted between H-Y and total airway length in class II and III malocclusions and between H-Y and upper airway length in class I malocclusions.
Conclusion: The position of the hyoid bone was associated with airway dimensions and should be considered during orthognathic surgery due to the risk of airway obstruction. ***(Imaging Sci Dent 2020; 50: 105-15)***

KEY WORDS: Hyoid Bone; Correlation of Data; Airway Management; Malocclusion; Cone-Beam Computed Tomography

Introduction

The development and proper functioning of the nasal cavity, nasopharynx, and oropharynx are interconnected with the normal growth pattern of the maxillofacial complex. Significant relationships have been reported between pharyngeal and dentocraniofacial structures.[1] Upper airway dimensions play a critical role in the airway obstruction and collapse that cause obstructive sleep apnea.[2,3]

Evidence shows that the craniofacial skeletal morphology may affect nasal respiratory function and the upper airway. Nasal airflow and nasal resistance are significantly higher in patients with skeletal class III malocclusion than in individuals with class I or class II malocclusion.[4] Certain skeletal characteristics, such as maxillary and mandibular retrusion or vertical maxillary excess in hyperdivergent patients, may be associated with smaller airway dimensions.[5] Patients with obstructive sleep apnea have lower pharyngeal resistance to collapse, and lateral and posterior wall collapse is also common among these patients.[6]

Recent investigations have revealed that individuals with

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class II malocclusion have narrower and smaller airways than those with class III malocclusion.[7] Mandibular setback retracts the hyoid bone and narrows the airway.[8,9]

The hyoid is a U-shaped bone located above the larynx and inferior to the base of the skull. It is connected to the posterior mandible and cranium by muscles and ligaments.[10] The hyoid bone plays a critical role in balancing the tension of the anterior and posterior occipital condyle muscles, leading to correct positioning of the head when standing. A significant correlation has been reported between changes in the posterior airway space and the hyoid bone position after mandibular advancement surgery.[11] As such, the position of the hyoid bone seems to affect the airway and should be considered in orthodontic diagnosis and treatment planning.[12]

Most previous studies have used lateral cephalograms to assess correlations between airway dimensions and the hyoid bone or skeletal patterns.[13-17] Although lateral cephalograms can provide valuable information, they have limitations inherent to the 2-dimensional (2D) visualization of 3-dimensional (3D) structures. Cone-beam computed tomography (CBCT) is a 3D imaging modality that provides high-quality images in the axial, coronal, and sagittal planes.[12,18,19]

Therefore, this study was performed to evaluate the position of the hyoid bone and its correlation with airway dimensions in different skeletal classes of malocclusion using CBCT.

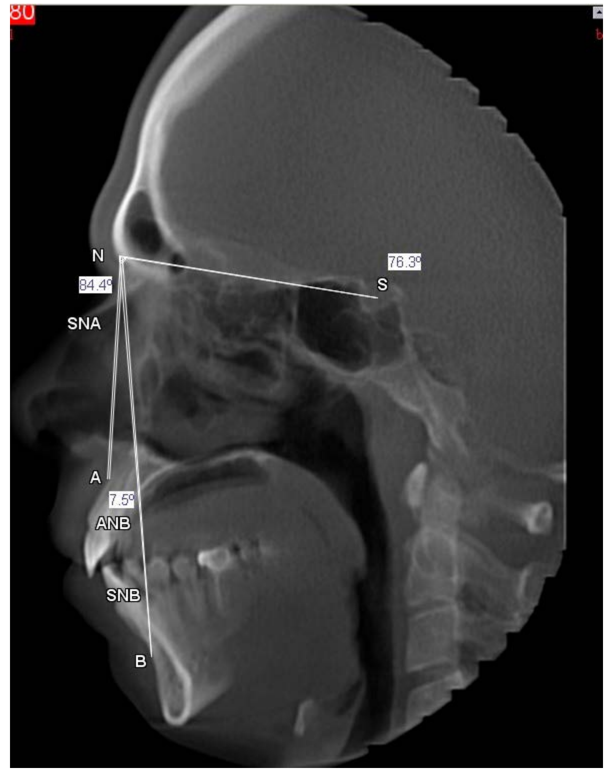

Fig. 1. SNA, SNB, and ANB angles are marked and calculated in order to determine the patient's malocclusion class. SNA: sella-nasion-A point, SNB: sella-nasion-B point, ANB: A point-nasion-B point.

Materials and Methods

This cross-sectional study evaluated 180 CBCT images of patients (118 women and 62 men) retrieved from the archives of the Dental School of Hamadan University of Medical Sciences. The images were originally taken between 2011 and 2018. Sample size was determined using PASS software v. 11 (NCSS LLC, Kaysville, UT, USA) for correlation studies. Assuming a study power of 80%, a level of significance of 0.05, and an attrition rate of 10%, we calculated a sample size of 52 for each group.

First, 556 CBCT scans retrieved from the university archives (from the period between 2011 and 2018) were observed by an examiner. According to the eligibility criteria, 180 images were selected using convenience sampling and were included in the study. The malocclusion class of the patient was determined on each CBCT image. According to the CBCT image analysis, the numbers of class I, class II, and class III patients were 52, 66, and 62, respectively. This study was approved by the ethics committee of Hamadan University of Medical Sciences (IR.UMSHA.REC.1396.619).

The inclusion criteria included an age of at least 18 years to ensure that growth and development had completed. To be included, the CBCT images must have been taken with a 13 cm × 16 cm field of view and a 0.3-mm voxel size, and the fourth cervical vertebra (C4) had to be visible. For imaging, the patients were in the supine position with the head and spine aligned. The head was rested on a foam pillow, keeping the neck in a neutral position, and was supported by a headrest. Each patient was asked to swallow once before exposure, hold his or her breath during the procedure, and close his or her mouth in maximum intercuspation occlusion. The exclusion criteria were pathological conditions of the pharynx, nasal obstruction, and a history of major orthodontic treatment.

The CBCT images were captured with a NewTom 3G CBCT system (QR srl, Verona, Italy) with exposure settings of 110 kVp and 3.2 mA. The images were archived in the Digital Imaging and Communications in Medicine format.

Reconstructed lateral cephalometric images were ob-

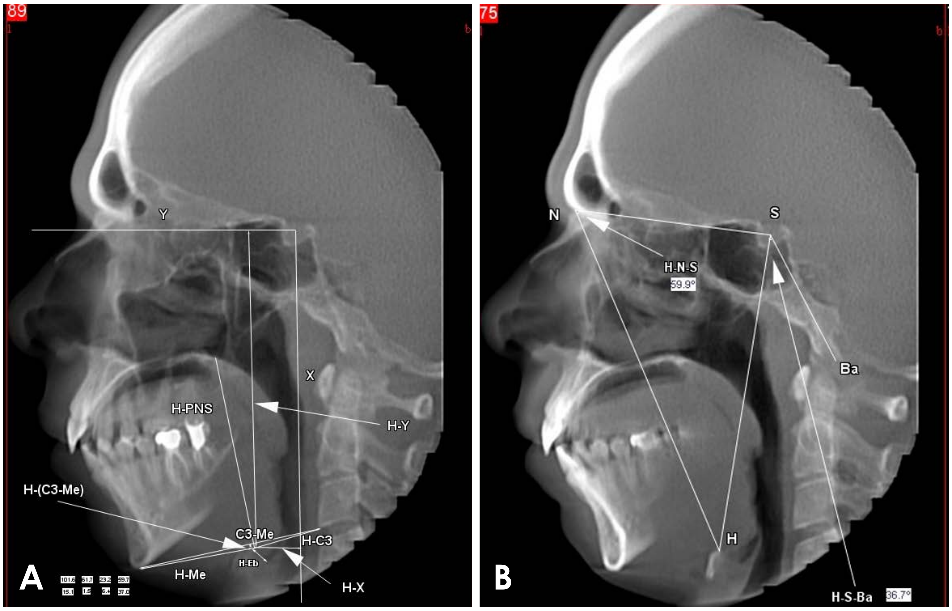

Fig. 2. A. Eight linear (C3-Me, H-Me, H-C3, H-EB, H-(C3-Me), H-PNS, H-Y, and H-X) hyoid parameters are marked and calculated on the reconstructed lateral cephalogram. B. Two angular (H-N-S and H-s-Ba) hyoid parameters are marked and calculated on the reconstructed lateral cephalogram.

Table 1. Cephalometric points used to measure hyoid parameters and the A point-nasion-B point (ANB) angle

Parameter	Definition
S	Sella
N	Nasion
Ba	Basion
A point	The deepest anterior point in the buccal surface of the body of the maxilla
B point	The deepest anterior point in the buccal surface of the body of the mandible
Me	Menton
ANS	Anterior nasal spine
Eb	The base of the epiglottis
H	The highest point of the hyoid bone
C3	The most anteroinferior point on the corpus of the third cervical vertebra
Ho	Hormion: the most posterior midline point on the vomer
Total airway length	The distance from the hard palate to the base of the epiglottis
Upper airway length	The distance between the upper border of the lower part of the pharynx and the point of minimum cross-sectional area of the airway
Airway volume	Region confined by 3 points (hormion, PNS, basion) and the line passing through the most anterosuperior point of C_4 and the posterior wall of the pharynx, parallel to the Frankfort plane
Morphology	Defined as the ratio of the minimum cross-sectional area of the airway to the mean cross-sectional area
Location	Defined as the ratio of upper airway length to total airway length
Mean cross-sectional area	Defined as the ratio of airway volume to airway length
Minimum cross-sectional area	Measured with Autodesk Meshmixer v. 3.0 3-dimensional analytical software

tained from the CBCT scans using NNT Viewer (QR srl) software via a direct volume rendering process. Then, the A point, the B point, and the nasion were identified by an examiner on the resultant lateral cephalogram. After selecting the File tab, the A point-nasion-B point (ANB) angle was calculated after manual dragging between the 3 points with point N (the nasion) as the vertex of the angle. Based on the ANB angle, the images were then categorized into those depicting class I, class II, and class III malocclusion. In total, 52 class I (ANB angle between 1° to 4°), 66 class II (ANB angle $\geq 4°$), and 62 class III (ANB angle $< 1°$) malocclusion cases were included in this study (Fig. 1).[20]

Next, the Frankfort plane was made parallel with the axial plane while the sagittal plane was aligned with the

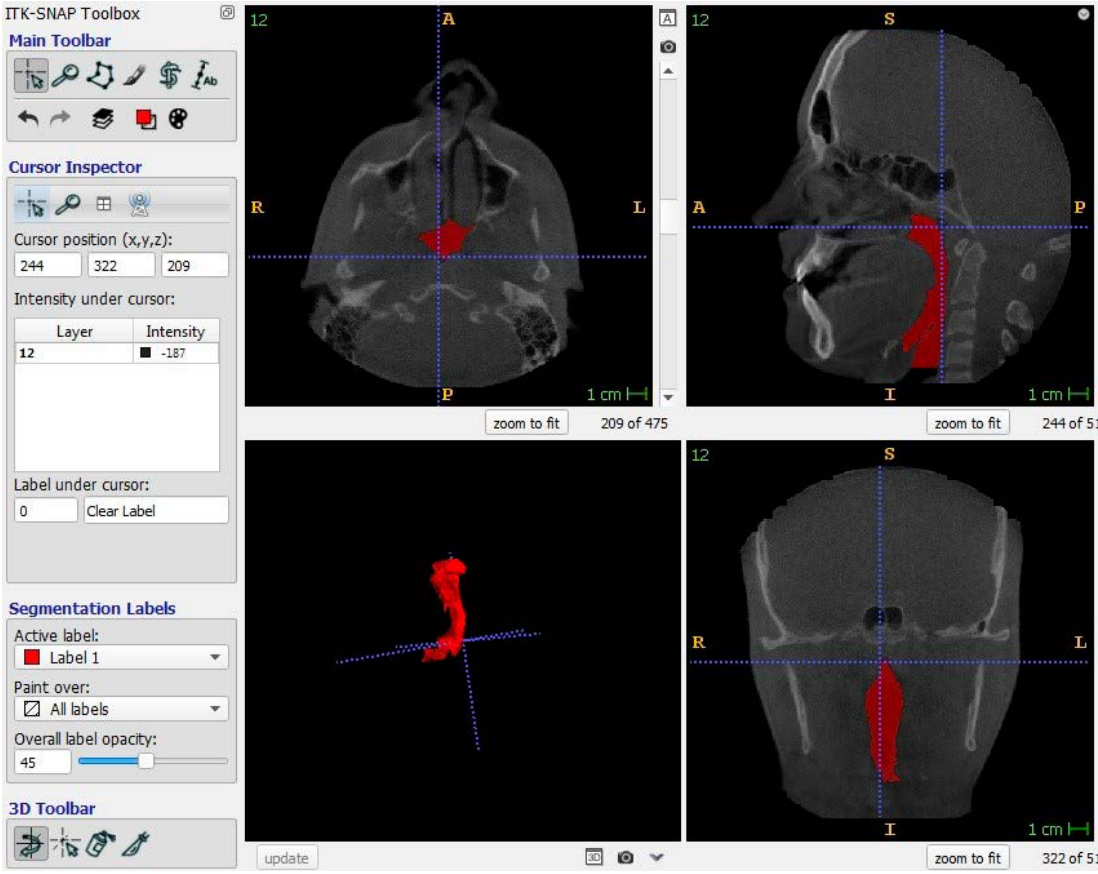

Fig. 3. A 3-dimensional model of the airway is reconstructed using ITK-SNAP software.

midline. The sagittal plane is the vertical line that passes through the ANS and the mid-posterior point of the spine termed the centrum. The Frankfort plane is the axial line that passes through the porion and orbitale points.

Eight linear and 2 angular hyoid bone parameters were measured (Fig. 2). The linear parameters included H-C3, H-EB, H-PNS, H-Me, H-X (the perpendicular distance from the hyoid bone to the vertical line passing through point S), H-Y (the perpendicular distance from H to the horizontal line passing through point S), H-(C3-Me), and C3-Me, while the angular parameters were H-S-Ba and H-N-S. The points involved in these measurements are defined in Table 1.

Airway volume, total airway length, and upper airway length were measured using ITK-SNAP version 3.6.0 (Penn Image Computing and Science Laboratory, Philadelphia, PA, USA) software. Total airway length was defined as the distance between the hard palate and the base of the epiglottis.[21] Upper airway length was measured as the distance between the upper border of the lower part of the pharynx and the point of minimum cross-sectional area of the airway. Airway volume was defined as the anatomical space confined by 3 points (the hormion, PNS, and basion) and the line passing through the most antero-

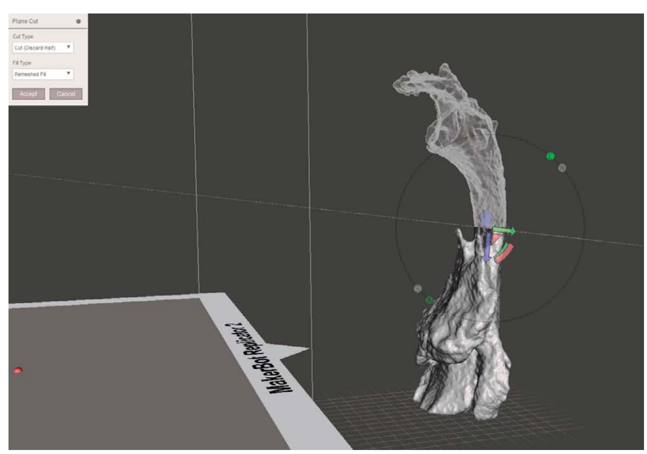

Fig. 4. The reconstructed model of airway is imported to Autodesk Meshmixer v. 3.0. Using the software's "plane cut" tool, the minimum cross-sectional area is marked manually and then calculated automatically.

Table 2. Comparison of airway parameters in different classes of skeletal malocclusion

Airway parameter	Skeletal class	n	Range	Mean	*F*	*P* value
Total airway length	Class I	52	55.7-85.4	74.4±6.6	1.94	$P>0.05$
	Class II	66	57.1-83.5	74.7±6.0		
	Class III	62	57.0-94.9	75.2±8.7		
Upper airway length	Class I	52	21.4-59.8	36.6±7.0	0.95	$P>0.05$
	Class II	66	18.1-59.4	35.1±9.7		
	Class III	62	22.6-38.2	96.0±466.1		
Volume	Class I	52	1091-7421	2117.7±1201.6	3.59	$P<0.05$
	Class II	66	1043-7421	2107.8±844.7		
	Class III	62	1009-9727	2826.6±2505.3		
Minimum cross-sectional area	Class I	52	1628.2-5983.2	2886.2±835.4	0.35	$P>0.05$
	Class II	66	1395.6-6183.6	2814.7±1051.4		
	Class III	62	1186.5-7846.7	2978.0±1318.5		
Mean cross-sectional area	Class I	52	14.6-129.9	28.9±19.3	2.77	$P>0.05$
	Class II	66	14.9-129.9	29.4±14.6		
	Class III	62	14.1-153.2	38.8±37.4		
Morphology	Class I	52	15.5-255.0	116.0±40.3	0.89	$P>0.05$
	Class II	66	15.5-217.6	106.0±45.5		
	Class III	62	10.5-314.4	117.6±64.5		
Location	Class I	52	0.3-0.8	0.4±0.0	0.92	$P>0.05$
	Class II	62	0.3-48.6	1.2±5.9		
	Class III	66	0.2-0.7	0.4±0.1		

superior point of C4 and the posterior wall of the pharynx, parallel to the Frankfort plane.[22]

Using this program, a 3D model of the airway was designed (Fig. 3). This model was subsequently used as raw data to calculate the minimum cross-sectional area of the airway using Autodesk Meshmixer v. 3.0 (Autodesk Inc., Mill Valley, CA, USA) software. By rotating the model spatially, the point of minimum cross-sectional area of the airway could be marked, and the area at that point could be calculated (Fig. 4).

Measurements were made by 2 observers (an oral and maxillofacial radiologist and a postgraduate student) twice each within a 2-week period. The images were viewed on a 20-inch monitor (LG, Seoul, Korea) in a semi-dark room, and the observers were allowed to change the contrast and brightness settings to optimize the viewing conditions as desired.

The collected data were entered into Excel software (Microsoft Corporation, Redmond, WA, USA) and were then imported into SPSS version 16 (SPSS Inc., Chicago, IL, USA) software for statistical analyses. Data were analyzed using analysis of variance followed by the Tukey *post hoc* test for multiple comparisons. The Pearson correlation test was applied to assess the correlations between the quantitative variables. All tests were conducted with $P<0.05$ considered to indicate statistical significance.

Results

The Cronbach alpha coefficient was calculated to assess the interobserver and intraobserver reliability. The levels of interobserver and intraobserver agreement were >80%.

A total of 180 CBCT scans of 118 women and 62 men were included in this study. They were divided into those depicting class I, class II, and class III malocclusion based on the ANB angle.

Table 2 shows the airway parameters measured in the different classes of skeletal malocclusion. Among the measured airway parameters, only the mean airway volume differed significantly among the 3 classes of malocclusion ($P<0.05$), with the smallest and largest airway volumes

Table 3. Comparison of hyoid parameters in different classes of skeletal malocclusion

Hyoid parameter	Skeletal class	n	Range	Mean	*F*	*P* value
C3-Me	Class I	52	63.1-100.3	76.7±8.3		
	Class II	66	54.6-90.7	72.8±8.0	14.23	$P<0.05$
	Class III	62	63.1-94.9	80.4±7.9		
C3-H	Class I	52	22-45.1	32.4±5.7		
	Class II	66	3.5-42.8	31.3±5.8	4.24	$P<0.05$
	Class III	62	27.1-41.1	34.0±3.7		
H-EB	Class I	52	4.6-27.7	10.3±4.3		
	Class II	66	5.1-28.1	10.7±4.6	12.58	$P<0.05$
	Class III	62	5.7-25.6	14.0±4.2		
H-PNS	Class I	52	41.5-72.2	57.0±8.2		
	Class II	66	41.8-77.3	60.1±8.3	6.55	$P<0.05$
	Class III	62	41.5-70.5	55.2±6.9		
H-Me	Class I	52	29.8-63.5	45.4±7.4		
	Class II	66	26.8-57.9	42.3±6.7	9.42	$P<0.05$
	Class III	62	29.8-74.5	47.9±7.8		
H-X	Class I	52	78.5-112.3	94.7±9.0		
	Class II	66	0-121.7	93.0±23.3	0.18	$P>0.05$
	Class III	62	79.2-112.7	93.6±8.4		
H-Y	Class I	52	0-68.4	17.6±13.1		
	Class II	66	2-45.2	16.5±10.8	0.20	$P>0.05$
	Class III	62	0-34.9	17.6±10.7		
H-(C3-Me)	Class I	52	0-31.8	6.2±5.5		
	Class II	66	0-14	5.5±3.6	0.61	$P>0.05$
	Class III	62	0-15.1	6.3±3.5		
H-S-BA	Class I	52	21.1-47.6	37.6±6.0		
	Class II	66	21.1-50.5	34.8±6.0	10.10	$P<0.05$
	Class III	62	29.1-58.8	40.2±7.9		
H-N-S	Class I	52	37.4-65.1	53.0±5.4		
	Class II	66	37.4-63.9	52.7±5.2	5.39	$P<0.05$
	Class III	62	44.1-89.5	56.0±7.7		

noted in patients with class II (2107.8±844.7 mm^3) and class III (2826.6±2505.3 mm^3) malocclusion, respectively. The Tukey test also showed that the mean airway volume among patients with class III malocclusion was significantly greater than that among those with class II malocclusion ($P<0.05$). The nominal power was also calculated using the observed data. According to the analysis, the power of the tests for the effect sizes obtained for each variable was greater than 0.80.

Table 3 includes the parameters related to hyoid bone position in the different skeletal malocclusion classes. Using analysis of variance, significant differences were found in the mean values of C3-Me, C3-H, H-Eb, H-Me, H-S-Ba, H-N-S, and H-PNS among the 3 classes ($P<0.05$). Using the Tukey test, the mean values of C3-H, H-Eb, H-S-Ba, and H-N-S were determined to be significantly lower among patients with class II malocclusion than among those with class III malocclusion, while the mean value of H-PNS in class II malocclusion cases was significantly greater than that in cases of class III malocclusion. No sig-

Table 4. Pearson correlation coefficients between airway and hyoid parameters in different classes of skeletal malocclusion

Hyoid parameters	Skeletal class	Airway parameters						
		Airway length	Upper airway length	Volume	Minimum cross-sectional area	Morphology	Location	Mean cross-sectional area
C3-Me	Class I	−0.05	0.22	0.10	0.18	−0.15	0.28*	0.08
	Class II	0.33*	−0.01	−0.15	−0.09	−0.003	−0.01	−0.18
	Class III	−0.29*	−0.40*	−0.03	−0.30*	−0.30*	−0.34*	−0.003
C3-H	Class I	0.14	0.53*	0.19	0.51*	0.14	0.53*	0.15
	Class II	0.51*	0.02	−0.16	0.33*	0.28*	0.02	0.21
	Class III	−0.04	−0.17	−0.001	−0.086	−0.11	−0.19	−0.003
H-EB	Class I	0.20	0.24	0.05	0.36*	0.40*	0.16	0.03
	Class II	0.20	−0.02	−0.03	−0.43*	−0.33*	−0.02	−0.01
	Class III	0.04	0.35*	0.02	0.53*	0.460*	0.34*	0.03
H-PNS	Class I	0.53*	0.28*	−0.28*	0.25	0.47*	0.03	−0.34*
	Class II	0.60*	0.07	0.04	0.38*	0.34*	0.06	−0.13
	Class III	0.45*	0.02	0.24	0.02	0.02	0.15	−0.29*
H-ME	Class I	−0.23	−0.08	0.03	−0.12	−0.33*	−0.02	−0.044*
	Class II	0.01	0.02	0.02	−0.15	−0.26*	−0.02	−0.003
	Class III	−0.23	−0.24	−0.01	−0.35*	−0.39*	−0.18	−0.02
H-X	Class I	0.54*	0.28	−0.39*	0.25	0.58*	0.02	0.44*
	Class II	0.01	0.06	−0.10	0.07	0.27*	0.06	−0.09
	Class III	0.40*	0.03	−0.031*	−0.04	−0.24	−0.12	−0.35*
H-Y	Class I	0.18	0.42*	−0.01	0.33*	0.22	0.38*	−0.04
	Class II	0.51*	0.11	0.05	0.27*	0.23	0.11	−0.12
	Class III	0.39*	0.22	−0.17	0.24	0.45*	0.08	−0.20
H-C3-Me	Class I	−0.28*	−0.01	0.30*	0.09	0.23	0.16	0.32*
	Class II	0.09	0.11	−0.13	0.22	0.19	0.11	0.18
	Class III	0.39*	0.22	−0.17	0.06	0.45*	0.08	−0.20
H-S-BA	Class I	−0.14	−0.01	−0.02	0.10	0.16	0.08	−0.03
	Class II	−0.05	−0.001	−0.07	−0.01	−0.03	−0.001	−0.04
	Class III	0.03	0.10	0.06	0.06	0.12	0.13	−0.06
H-N-S	Class I	0.22	0.19	0.19	0.19	0.50*	0.09	−0.26
	Class II	0.26*	−0.06	−0.06	−0.06	−0.27*	−0.07	0.06
	Class III	−0.04	0.30*	−0.12	0.34*	0.27*	0.37*	−0.11

*: $P<0.05$. All data provided are Pearson correlation coefficients (r-values).

nificant differences were observed between the mean values of H-X, H-Y, and H-(C3-Me) among the 3 groups.

Table 4 shows the Pearson correlation coefficients for the correlations between the airway and hyoid parameters in the 3 malocclusion classes. Each of the airway parameters showed significant correlations with certain measurements of hyoid bone position; the significance of these correlations often differed according to the class of malocclusion, although some combinations of airway parameters and hyoid measurements lacked significant correlations across all 3 groups.

In patients with class I malocclusion, the airway volume was positively correlated with H-(C3-Me) and inversely correlated with H-PNS and H-X. The airway volume was similarly inversely correlated with H-X in class III malocclusion cases. No significant correlations were found between the airway volume and hyoid parameters in cases of class II malocclusion.

In all 3 malocclusion classes, H-Eb was positively correlated with the minimum cross-sectional area and the airway morphology. H-PNS was also positively correlated with the total airway length. A significant positive correlation was additionally found between H-Y and the total airway length in class II and class III malocclusion cases and between H-Y and the upper airway length in class I malocclusion cases.

Discussion

Many studies have used lateral cephalograms to assess the correlations between airway dimensions and various skeletal patterns.[13-17]

Reconstructed lateral cephalograms obtained from CBCT images were used in the present study. The reconstruction process, which is classified as a direct volume rendering technique, involves creating an image slice that represents a specific volume of the patient. Full-thickness volume rendering of images in the sagittal plane can be used to generate simulated skull projections, such as lateral cephalometric images. These reconstructed images lack magnification and parallax distortion. However, this technique involves use of the entire volumetric data set, and its interpretation is adversely affected by anatomic noise and the superimposition of multiple structures, issues that are also present in conventional projection radiography.[23]

Kaur et al.[24] compared the reliability of lateral cephalography and computed tomography in the assessment of airway space and concluded that the measurements acquired from both modalities are reliable and reproducible, but computed tomography provides a better assessment of the cross-sectional dimensions of the airway.

The results of studies that used conventional lateral cephalograms to measure airway dimensions are consistent with those of the present study. For instance, in one study, the pharyngeal depth was found to be greater in patients with skeletal class III malocclusion than in patients with skeletal class I malocclusion.[14]

A study comparing the accuracy of linear measurements taken using lateral cephalograms obtained from CBCT scans with measurements taken using digital conventional lateral cephalometric radiography showed a statistically significant difference from the actual distance in lateral cephalometry for most linear measurements. In contrast, none of the landmarks on CBCT displayed a significant difference from the actual value. This indicates that CBCT seems to be more accurate than conventional lateral cephalometry.[25]

In cephalometry, anatomical structures are visualized on 2D images; such visualization is associated with issues including superimposition and asymmetric magnification, which make measurement more difficult. Asymmetric magnification occurs due to the projection geometry of lateral cephalometry. With this technique, exact superimposition of the right and left sides is impossible because the structures on the side nearer the image receptor are magnified less than the same structures on the side more distant from the receptor.[23] The superimposition of structures is another unfavorable phenomenon that is inevitable with 2D imaging modalities.

CBCT is a rather recent technology that enables the 3D visualization of airway structures. It produces images without any superimposition or magnification. CBCT images have sub-millimeter resolution (0.076- to 0.125-mm voxel resolution),[23] which leads to higher image quality and facilitates the identification of anatomical landmarks and spaces.

Gribel et al.[26] assessed the accuracy and reliability of craniometric measurements on lateral cephalograms and 3D measurements on CBCT scans. They concluded that CBCT craniometric measurements were accurate to a subvoxel size and can potentially be used as a quantitative diagnostic tool, while 2D cephalometric norms cannot be readily used for 3D measurements because of differences in accuracy between those measurements and the gold standard (direct measurement). In summary, CBCT is more useful than 2D imaging modalities for airway assessment and can serve as a strong diagnostic tool for this purpose.

Recently, a group of authors used CBCT to study the upper airway.[4] Although magnetic resonance imaging has higher soft tissue resolution than CBCT, this imaging modality has key disadvantages of limited access and expensive equipment.[27] Thus, in the present study, we used CBCT and ITK-SNAP and Meshmixer software programs to evaluate and study the airway morphology in different skeletal malocclusion classes. Of the airway parameters evaluated, only the airway volume differed significantly among the 3 types of skeletal malocclusion (Table 2). Class III and class II malocclusions were associated with the largest and smallest airway volumes, respectively, which could be the result of the horizontal position of the mandible affecting the position of the hyoid bone.

Jayaratne and Zwahlen[28] assessed the CBCT scans of 62 patients with skeletal class II or class III malocclusion to compare the anthropometric dimensions of the oropharyngeal airway in young adults. They performed volumetric, linear, and surface area measurements using 3dMDvultus software, in contrast to the ITK-SNAP software used in the present study. The airway borders were also outlined differently in the 2 studies. In the study by Jayaratne and Zwahlen, the superior border of the airway was defined as the horizontal line passing through the PNS parallel to the SN line, and the inferior border was defined as the line passing through the base of the epiglottis parallel to the SN line. In contrast, in the present study, the most inferior and superior borders were defined as the line passing through the most superior-anterior point of C_4 and the line passing through the junction between the vomer and the sphenoid bone, respectively. Despite these differences, Jayaratne and Zwahlen reported that the mean airway volume in patients with class III malocclusion was significantly larger than that in patients with class II malocclusion, which was consistent with the results of our study.

In a study by Kim et al.,[29] the cross-sectional area and the volume of the airway were measured in 27 children with a mean age of 11 years using CBCT. The authors reported that the total airway volume (including the nasal cavity, nasopharynx, and oropharynx) was significantly smaller in retrognathic children than in the group with normal craniofacial growth. However, the volume of the lower structures was not significantly different between the 2 groups. Similarly, some other studies have reported significantly smaller airway volume in patients with class II malocclusion than in those with other classes of skeletal malocclusion.[10,30]

Iwasaki et al.[31] examined the oropharyngeal airway in 20 children with class III malocclusion and 25 children with class I malocclusion. They reported that children with class III malocclusion had significantly larger airway cross-sectional areas than children with class I malocclusion. They also found that the cross-sectional area of the airway was correlated with the severity of the class III malocclusion. Despite the difference in the ages of the participants (as subjects under 18 years of age were excluded from the present study), the results of Iwasaki et al. are consistent with those of the present report. The method of airway segmentation was similar across the 2 studies; however, we did not calculate the volume of the nasal cavity.

It can be inferred that in class III malocclusions, the mandible is positioned anteriorly, and therefore, the muscles and ligaments attached to the jaw cause similar anterior positioning of the hyoid bone; consequently, the airway dimensions increase.

The results of the present study revealed significant differences in the hyoid parameters of C3-H, H-Eb, H-PNS, H-Me, H-S-Ba, and H-NS among different classes of skeletal malocclusion. In the present study, the mean values of C3-Me and C3-H in patients with class II malocclusion were smaller than the corresponding values in the other groups. Mortazavi et al.[32] and Bedoya et al.[33] similarly reported that the C3-H distance was significantly smaller in class II patients than in the other groups.

Lakshmi et al.[34] assessed the pharyngeal width and growth pattern in different classes of skeletal malocclusion. They reported that airway width, as assessed on 60 lateral cephalograms, was significantly different in class I and class II patients. In our study, however, no significant difference in this parameter was observed among the malocclusion classes.

Based on our findings, the H-Me distance was inversely correlated with the minimum cross-sectional area in patients with class III malocclusion. In fact, a reduction in hyoid-to-mandibular symphysis (Me) distance was associated with an increase in the minimum cross-sectional area of the airway. Moreover, H-PNS was correlated with airway length in all 3 malocclusion classes.

Jiang[12] assessed correlations between the position of the hyoid bone and airway dimensions in 254 Chinese adolescents using CBCT. The age range of the patients and the software program (MIMICS) used to analyze the parameters in that study differed from those in the present study. However, Jiang measured the same hyoid and airway parameters as in the present study. In the study by Jiang,[12] the airway length, width, and volume were found to be positively correlated with H-Me, H-(C3-Me), H-Y, C3-Me, C3-H, and H-PNS and to be inversely correlated with H-S-Ba and H-Eb. The H-X and H-Eb measurements were inversely correlated with the airway volume, the minimum and mean cross-sectional area, and the anteroposterior and mediolateral diameters. However, in the present study, the airway volume was found to be inversely correlated with H-PNS in patients with class I malocclusion, and H-PNS was significantly correlated with most of the other airway parameters.

A supine CBCT scanner was used in the present study based on the fact that the soft palate epiglottis and the entrance of the esophagus move caudally when the patient's position changes from supine to upright and move posteriorly when that position changes from upright to supine. The hyoid bone moves caudally but not posteriorly in response to the same changes in position.[28] Therefore, the calculated airway dimensions in our study may differ from the corresponding values in other studies that used upright or seating CBCT scanners; however, since the findings were assessed comparatively, this would not affect the final results.

One major limitation of the present study was patient collection based on our inclusion criteria. Large field-of-view CBCT is mostly ordered for patients after orthognathic surgery, for those with cleft lips or palates, or for those who have undergone major orthodontic treatment; however, such cases were excluded from the study, since their normal anatomy had been altered. Many additional patients were also excluded because of poor CBCT image quality. Another limitation of this study related to the use of software programs such as ITK-SNAP. In order to design the 3D airway model in ITK-SNAP, all of the borders had to be dragged by the examiner, and the software then automatically filled the confined area based on a predetermined algorithm. However, in some cases, voids and extra spots were present in the extracted model due to software bugs. These voids were repaired and filled, and the extra points were erased manually by the examiner, in a process that was complex and time-consuming. Designing software specifically for airway measurements can address this problem.

In conclusion, the positioning of the hyoid bone and the anteroposterior jaw affected the airway dimensions and should be taken into account during orthognathic surgery. This particularly applies to the mandibular setback surgery of patients with class III malocclusion, as this procedure results in posterior movement of the hyoid bone and can constrict the airway. Due to the risk of sleep apnea and airway obstruction, the airway condition in such patients should be evaluated prior to any surgical intervention to prevent unwanted complications.

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