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. Upper airway dimensions play a critical role in the airway obstruction and collapse that cause obstructive sleep apnea.

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. Certain skeletal characteristics, such as maxillary and mandibular retrusion or vertical maxillary excess in hyperdivergent patients, may be associated with smaller airway dimensions. Patients with obstructive sleep apnea have lower pharyngeal resistance to collapse, and lateral and posterior wall collapse is also common among these patients.

Recent investigations have revealed that individuals with...
class II malocclusion have narrower and smaller airways than those with class III malocclusion. Mandibular setback retracts the hyoid bone and narrows the airway.

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. 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. As such, the position of the hyoid bone seems to affect the airway and should be considered in orthodontic diagnosis and treatment planning.

Most previous studies have used lateral cephalograms to assess correlations between airway dimensions and the hyoid bone or skeletal patterns. 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.

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.

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-
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Obtained 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 select-
ing 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 ≥ 4°), and 62 class III (ANB angle < 1°)
malocclusion cases were included in this study (Fig. 1).

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

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 C4 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 |
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. 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-
superior point of C4 and the posterior wall of the phar-
ynx, parallel to the Frankfort plane.22

Using this program, a 3D model of the airway was de-
signed (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 (Mi-
crosoft 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 quantita-
tive variables. All tests were conducted with \( P < 0.05 \)
considered to indicate statistical significance.

### Results

The Cronbach alpha coefficient was calculated to as-

**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|     |         |

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

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 | 14.23  | <0.05   |
|                 | Class II       | 66 | 54.6-90.7   | 72.8±8.0 | 4.24   | <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 |        |         |
|                 | Class III      | 62 | 27.1-41.1   | 34.0±3.7 |        |         |
| H-EB            | Class I        | 52 | 4.6-27.7    | 10.3±4.3 | 12.58  | <0.05   |
|                 | Class II       | 66 | 5.1-28.1    | 10.7±4.6 |        |         |
|                 | 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 |        | <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   | <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 | 0.18   | >0.05   |
|                 | Class II       | 66 | 0-121.7     | 93.0±23.3|        |         |
|                 | Class III      | 62 | 79.2-112.7  | 93.6±8.4 |        |         |
| H-Y             | Class I        | 52 | 0-68.4      | 17.6±13.1| 0.20   | >0.05   |
|                 | Class II       | 66 | 2.45.2      | 16.5±10.8|        |         |
|                 | Class III      | 62 | 0-34.9      | 17.6±10.7|        |         |
| H-(C3-Me)       | Class I        | 52 | 0-31.8      | 6.2±5.5  | 0.61   | >0.05   |
|                 | Class II       | 66 | 0-14        | 5.5±3.6  |        |         |
|                 | Class III      | 62 | 0-15.1      | 6.3±3.5  |        |         |
| H-S-BA          | Class I        | 52 | 21.1-47.6   | 37.6±6.0 | 10.10  | <0.05   |
|                 | Class II       | 66 | 21.1-50.5   | 34.8±6.0 |        |         |
|                 | 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 | 5.39   | <0.05   |
|                 | Class II       | 66 | 37.4-63.9   | 52.7±5.2 |        |         |
|                 | Class III      | 62 | 44.1-89.5   | 56.0±7.7 |        |         |

noted in patients with class II (2107.8±844.7 mm³) and class III (2826.6±2505.3 mm³) 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-
significant 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

| Hyoid parameters | Skeletal class | 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                        | 0.15       | 0.29*    | -0.02                    |
| 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).
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 cephalogram 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.26

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.3 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 Zwahlen28 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 C4 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., 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. Moreover, H-PNS was correlated with airway length in all 3 malocclusion classes.

Jiang 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, 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. 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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Conflicts of Interest: None

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