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RESEARCH ARTICLE

# Correlation between the three-dimensional maxillomandibular complex parameters and pharyngeal airway dimensions in different sagittal and vertical malocclusions

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**Objectives:** This study aimed to determine the three-dimensional (3D) correlation between maxillomandibular complex parameters and pharyngeal airway dimensions in different sagittal and vertical malocclusions.

**Methods:** This retrospective cross-sectional study included the CBCT scans of 368 patients with a mean age of 23.81 ± 3.01 years. The patients were classified into three groups (skeletal Class I, II, and III). Each class group was divided into three subgroups based on vertical growth patterns (hypo-, normo-, and hyperdivergent). The maxillomandibular complex was evaluated in the three planes using 16 skeletal measurements. Naso-, oro-, hypo-, and total pharyngeal airway spaces were assessed in terms of width, volume, surface area, and minimum constricted area (MCA). Two-way ANOVA followed by the Bonferroni post-hoc test were used.

**Results:** The nasopharyngeal airway space was significantly lowest regarding sagittal and lateral widths in the skeletal Class III patients, the lowest volume and surface area were in hyperdivergent patients, and MCA was the highest in Class II and hypodivergent patients. The oro- and hypopharyngeal sagittal width, volume, surface area, and MCA were the lowest in the hyperdivergent patients, and oropharyngeal lateral width and hypopharyngeal sagittal width were the highest in skeletal Class III. The total pharyngeal volume, surface area, and MCA were the lowest in the hyperdivergent patients, and skeletal Class II patients had the lowest MCA.

**Conclusions:** The pharyngeal airway dimensions differ with various sagittal and vertical malocclusions. These differences could apply to diagnosis, treatment planning, and possible changes following orthodontic/orthopedic or surgical treatment.

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## Introduction

The upper airway is a hollow space surrounded by hard and soft tissue structures. This complex and highly dynamic structure contributes to various actions like breathing, swallowing, and speaking; thus, it is critical to assess this dynamic space properly.[1]

Craniofacial growth and development involve complex mechanisms and multifactorial structures. Since the early 20th century, researchers have studied the relationship between craniofacial structures and respiratory functions.[1] The most widely accepted theory for craniofacial growth and development is Moss's functional matrix theory, which notes that most craniofacial growth and development is devoted to regulating the functional behavior of the surrounding soft tissues.[2] Angle et al[1] proposed that the function and anatomy of the pharyngeal airway strongly influence craniofacial growth and development. Consequently, any discrepancies in normal respiration through active craniofacial development can result in speech abnormalities, abnormal craniofacial development, and dental malocclusion. Previous studies have linked skeletal malocclusion to airway morphology changes and vice versa.[3] Therefore, pharyngeal airway evaluation is important in diagnosing positional and structural dentofacial patterns.

Through the extensive use of CBCT and advancement in medical care, pharyngeal airway evaluation has recently received much attention in the orthodontics.[4] Several studies have evaluated airway measurements and their effects on craniofacial growth and development; some of these studies rely on lateral cephalogram (LC) analysis,[3,5–9] while some are based on many CBCT radiographic images.[10–23] CBCT allows the three-dimensional (3D) visualization and measurement of complex pharyngeal airway anatomy with less exposure to radiation and highly precise multiplanar and volumetric measurements of the pharyngeal airways.[24]

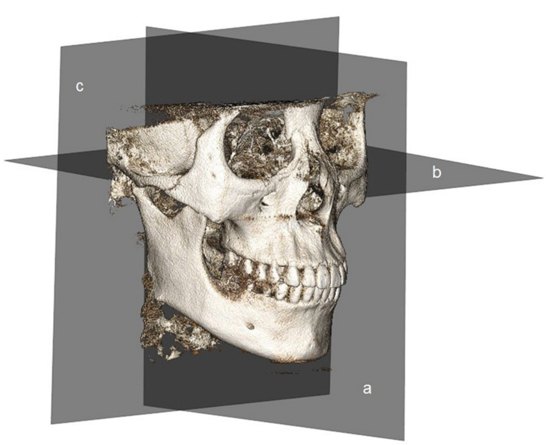


**Figure 1** The 3D coordinate system. (a) The midsagittal plane constructed by the nasion and basion point and incisive foramen. (b) The horizontal plane: constructed by the right and left porions and the right orbitale. (c) The vertical plane constructed by the basion point and perpendicular to the horizontal and midsagittal plane.

CBCT studies in this context have yielded inconsistent and contradictory findings.[10–16,18–22] The primary reasons for these discrepancies include inconsistent methodologies, variations in airway measurement sites, and study sample diversity.[25] Differences in such studies when assessing the airway during variable growth periods,[12,19] taking malocclusion into account, disregarding the impact on airway measurements,[14,22] or there are limited CBCT studies to evaluate sagittal and vertical craniofacial dimensions and ignoring the transverse dimension,[12,19] two multiplanar image-based segmentation[14] and airway saturation value was not being considered.[26] The associations between the maxillary and mandibular sagittal and vertical positions significantly impact the pharyngeal airway, with few reports about the detailed offending dimension in the 3D complex region.[21]

The current study aimed to minimize these variations by making a comprehensive case selection, presentation, and pharyngeal airway assessment; this study aimed to determine the 3D correlation between the maxillomandibular complex parameters and the pharyngeal airway dimensions in different sagittal and vertical malocclusions.

## Methods

### *Sample selection*

This retrospective cross-sectional study was approved by the ethics committee of the Hospital of Stomatology, Lanzhou University (No: LZUKQ-2019-056), and written informed consent was obtained from all participants upon registration in the institutional database. The inclusion criteria were as follows: (1) aged 18–28 years old, (2) normal nasal breathing, (3) normal body mass index (BMI ) , (4) craniocervical inclinations were limited from 90° to 110° to minimize the head posture impact on pharyngeal airway measurements, and (5) good quality CBCT images. The exclusion criteria included: (1) history of temporomandibular joint disorders symptoms, (2) previous orthodontic treatment or orthognathic surgery, and (3) skeletal abnormalities in the craniofacial region.

### *Sample size*

The sample size was determined using the G*power 3.0.10 software with an $\alpha$ level of 0.05 and a power level equal to 90%. The estimate is based on the study by Paul et al,[27] where the mean oropharyngeal volume was 13240.1 ± 5112.1 and 7816.9 ± 2767.0 $mm^3$ for skeletal Class I and II, respectively. A study by Wang et al[28] revealed that the mean glossopharyngeal volume was 5997.06 ± 1674.9 and 4412.97 ± 972.9 $mm^3$ for average and high growth patterns, respectively. The resulting sample size was 11 and 14 patients in each group. The minimum number of subjects included in this study in any subgroup was 40.

### *Three-dimensional CBCT protocol*

CBCT images were acquired using the I-CAT Image System (Imaging Sciences International Inc. Hatfield)

**Table 1** Definitions of anatomical landmarks, reference lines and planes, and pharyngeal airway borders

| | *Name* | *Abbreviation* | *Definition* |
|---|---|---|---|
| Anatomical Landmarks | Nasion | N | That represents of nasofrontal structure in the midline |
| | Sella | S | The midpoint of the sella turcica |
| | Basion | Ba | The most inferoposterior of the foramen magnum is in the midline of the skull base |
| | Subspinale | A | The most concavity point in the upper labial alveolar process |
| | Incisive foramen | IF | The center of incisive foramen centered mediolateral, exists posterior to the central incisors at maxillary mid palatine |
| | Posterior nasal spine | PNS | The distal midpoint of the posterior nasal spine of the palatine bone |
| | Right/Left Jugular | JR/JL | That represents a bilateral point on the jugular process at connecting the maxilla tuberosity outline and the zygomatic buttress |
| | Supramentale | B | The deepest point of the mandibular symphysis |
| | Menton | Me | The most inferior point on mandibular symphysis |
| | Gnathion | Gn | The most anteroinferior aspect of the mandibular symphysis |
| | Right/Left Porion | PoR/L | The right or left most superior point of the external auditory meatus |
| | Right/Left Orbitale | OrR/ L | The lowest point on each orbit's right and left is at the infraorbital margin. |
| | Right/Left Gonion | GoR/ L | The midpoint at the gonial angle is traced by bisecting the mandible's posterior and inferior borders on each angle |
| | Right/Left Condylion | CoR/L | The most posterosuperior point on the outline of the right/left mandibular condyle |
| | second cervical vertebra | C2a | The second cervical vertebra's most anteroinferior point |
| | third cervical vertebra | C3a | The third cervical vertebra's most anteroinferior point |
| | second cervical vertebra | C2p | The second cervical vertebra's most posteroinferior point |
| | third cervical vertebra | C3p | The third cervical vertebra's most posteroinferior point |
| | Nasopharyngeal anterior and posterior points | NP (A/P) | The most anterior (NP-A) and posterior points (NP-P) in the PNS plane are in the axial view |
| | Oropharyngeal anterior and posterior points | OP(A/P) | The most anterior (OP-A) and posterior points (OP-P) in the C2 plane are in the axial view |
| | Hypopharyngeal anterior and posterior points | HP(A/P) | The most anterior (HP-A) and posterior points (HP-P) in the C3 plane are in the axial view |
| | Nasopharyngeal left and right lateral points | NP(L/R) | The most lateral left (NP-L) and lateral right (NP-R) points in the PNS plane in the axial view |
| | Oropharyngeal left and right lateral points | OP(L/R) | The most lateral left (OP-L) and lateral right (OP-R) points in the C2 plane in the axial view |
| | Hypopharyngeal left and right lateral points | HP(L/R) | The most lateral left (HP-L) and lateral right (HP-R) points in the C3 plane in the axial view |
| Reference line and planes | Horizontal plane | FH | Passed through the right and left part (Po-R/L) and the right orbital portion (Or-R) |
| | Midsagittal plane | MSP | Passed through points N, Ba, and IF |
| | Vertical plane | VP | Passed through the basion point and is perpendicular to the FH |
| | Nasion perpendicular plane | N-FH Prep | Passed through nasion (N), representing a true vertical reference plane perpendicular to FH |
| | Sella-nasion line | SN Line | The line passes between the S and N points |
| | Cervical line | C2p-C3p line | The line passes between the C2p and C3p points |
| | Mandibular plane | MP | Defined by three landmarks: gnathion, right, and left gonion |
| | Posterior nasal spine plane | PSN Plane | Passed through PNS, describing and paralleling the plane of the FH |
| | second cervical vertebra plane | C2 Plane | Passed through C2, describing and paralleling the plane of the FH |
| | third cervical vertebra plane | C3 Plane | Passed through C3 represents and is parallel to the FH |

(Continued)

**Table 1** (Continued)

| | *Name* | *Abbreviation* | *Definition* |
|---|---|---|---|
| Pharyngeal airway borders | The anterior border of the NP | | Passed through the PNS point perpendicular to the FH |
| | The inferior border of the NP | | Parallel to the FH through the PNS and perpendicular to the sagittal plane |
| | The superior border of the OP | | The inferior border of the NP |
| | The inferior border of the OP | | Parallel to the palatal plane intersecting the most anteroinferior point of the second cervical vertebrae (C2a) |
| | The superior border of the HP | | The inferior border of the OP |
| | The inferior border of the HP | | Parallel to the palatal plane intersecting the most anteroinferior point of the third cervical vertebrae (C3a) |
| | The posterior border | | The posterior wall of the pharyngeal |

with the following acquisition parameters: field of view (17.0 × 13.0cm); 120 kV; 18.54 MAs, 8.9 exposure time, and the image voxel size was 0.3mm. The scanning was done with maximum intercuspation, standardized head position, the Frankfort plane parallel to the floor, and no swallowing. The patients were instructed to swallow once before each exposure and hold their breath during the scan. The DICOMs (Digital Imaging and Communications in Medicine ) of the CBCT images were collected and then imported into InVivo 6.0.3 (Anatomage, San Jose, CA) for skeletal measurements (maxilla and mandible). In contrast, the Dolphin 11.8 system (Dolphin Imaging and Management Solutions, Chatsworth, CA) was used for pharyngeal airway segmentation and measurements. The CBCT images were reoriented using coordinate system orientation, as shown in Figure 1, depending on the central landmarks chosen by Nasion, Incisive Foramen, and Basion; Orbital and Porion determined the horizontal landmarks, and the vertical landmark was according to the Basion point.[29,30]

*Skeletal measurements*

The skeletal anatomical landmarks, reference lines, and planes are shown in Table 1 and the skeletal measurements are shown in Table 2. The subgroup distribution was evaluated using four measurements depending on Chinese norms; [31,32] the ANB° and AF-BF mm, to determine whether the patient classified as skeletal Class I, II, and III malocclusions where 0.7 ° ≤ ANB ≤ 4.7° and 0.8mm ≤ AF B ≤ 6.4mm were considered skeletal Class I, ANB > 4.7° and AF-BF > 6.34mm were considered skeletal Class II, and ANB < 0.7° and AF-BF > 0.8mm were considered as skeletal Class III. For determination of vertical pattern; GoGn-SN° and SGo/NMe% were used to determine whether the patient belonged to hypo-, normo-, and hyperdivergent groups where 27.3° < GoGn SN < 37.7° and 62% < SGo/NMe < 68% considered normodivergent, GoGn-SN ≥ 37.7° and SGo/NMe ≤ 62% considered hyperdivergent, and GoGn-SN ≤ 27.3° and SG/NMe ≥ 68% considered hypodivergent growth patterns.

*Pharyngeal airway measurements*

The pharyngeal anatomical landmarks, reference lines and planes, pharyngeal airway borders are shown in Table 1, and pharyngeal airway space measurements are summarized in Table 2. The naso-, oro-, hypo-, and total pharyngeal airway space measurements are shown in Figures 2–5, respectively. A sinus/airway module was used for the segmentation protocol, and the slice was chosen so that the optimum airway view coincided with the midsagittal plane.[18] The pharyngeal airway area was then marked with seed points used to expand the airway. As recommended in previous studies, the sensitivity was set at 72 or 73.[27,33] The chipping boundaries were added to restrict this extension. This method combines automated and manual segmentation and exploits the strengths of each segment.

54 CBCTs were chosen randomly and measured independently by two examiners over two 2-week periods to ensure the reading's reliability. All measurements were performed under the supervision and guidance of oral and maxillofacial radiologists with more than 10 years of experience.

*Statistical analysis*

The IBM SPSS Statistics, v. 24 for Windows (IBM Corp., Armonk, NY) was used to analyze the data. The intraclass correlation coefficient (ICC) and absolute and relative technical measurement errors (TEM and rTEM) were used to evaluate the reproducibility and reliability of skeletal and pharyngeal airway measurements. The skewness test was used to determine the normality of the data. Descriptive statistics were calculated and presented, including each variable's standard and mean deviations. Two-way ANOVA was used, and the Bonferroni post-hoc test was used when significant. $p \leq 0.05$ was chosen as the statistical significance level.

## Results

In total, 368 patients were involved in the study. Table 3 shows the chosen patients' age, sagittal and vertical skeletal relationship characteristics. Intra- and inter-examiner reliability were high, where both intra- and interobserver R and ICC values were higher than 0.95, presented in Table 4.

**Table 2** The skeletal and pharyngeal airway measurements used in this study

| *Measurements* | | *Name* | *Definition* |
|---|---|---|---|
| Jaws relationship | Sagittal | ANB ° | The angle between three points, A, N, and B points |
| | | AF-BFmm | The line between the A-FH and B-FH |
| | Vertical | SGo /NMe % | The ratio between the posterior facial height (S-Go) and the anterior facial height (N-Me) |
| | | GoGn-SN ° | An angle between the S-N line and the MP |
| Cranio-cervical inclination | | OP/SN ° | An angle between the S-N line and the C2p-C3p line |
| | Sagittal position | SNA ° | The angle between three points S, N, and B. |
| Maxilla | Sagittal position | A-NV mm | A line between point A and the NV Plane |
| | Effective length | Co-A mm | An average of the bilateral linear distance between Co and A points. |
| | Width | JL-JR mm | The line between JR and JL points |
| | Vertical position | A-FH mm | A line from point A to FH plane |
| Mandible | Sagittal position | SNB° | The angle between three points S, N, and B. |
| | Sagittal position | B-NV mm | The line between point B and the NV plane |
| | Body length | Gn –Go mm | The average of the bilateral linear distance from the Go and Gn points |
| | Effective length | Co-Gn mm | An average of the bilateral linear distance from the Co and Gn points |
| | Width | GoR-GoL mm | A line from the GoR and GoL points |
| | Vertical position | B-FH mm | A line from B point and horizontal plane |
| Nasopharyngeal | Sagittal width | NP(A-P) mm | The line between NPA and NPP points at the PNS plane in axial view |
| | Lateral width | NP(L-R) mm | The line between NPL and NPR points at the PNS plane in axial view |
| | Volume | NP-V $mm^3$ | Measured between R point and PNS plane at the midsagittal plane |
| | Area | NP-A $mm^2$ | The area at the midsagittal plane between the R point and PNS plane |
| | Minimum constriction area | NP-MCA $mm^2$ | Nasopharyngeal airway minimum constricted area |
| Oropharyngeal | Sagittal width | OP (A-P) mm | The line between OPA and OPP at the C2plane in axial view |
| | Lateral width | OP (L-R) mm | The line between OPL and OPR at the C2plane in axial view |
| | Volume | OP-V $mm^3$ | Measured between PNS and C2 planes in sagittal, coronal and axial view |
| | Area | OP-A $mm^2$ | Measured between PNS and C2 planes at the midsagittal plane |
| | Minimum constriction area | OP-MCA $mm^2$ | Oropharyngeal airway minimum constricted area |
| Hypopharyngeal | Sagittal width | HP (A-P) mm | The line between HPA and HPP at the C3 plane in axial view |
| | Lateral width | HP (L-R) mm | The line between HPL and HPR at the C3 plane in axial view |
| | Volume | HP-V $mm^3$ | Measured between C2 and C3 planes in sagittal, coronal and axial view |
| | Area | HP-A $mm^2$ | Measured between C2 and C3 planes at the midsagittal plane |
| | Minimum constriction area | HP-MCA $mm^2$ | Hypopharyngeal airway minimum constricted area |
| Total pharyngeal | Volume | TP-V $mm^3$ | Measured between the roof of nasopharyngeal and C3 plane at the midsagittal plane |
| | Area | TP-A $mm^2$ | Measured between the roof of nasopharyngeal and C3 plane at the midsagittal plane |
| | Minimum constriction area | TP-MCA $mm^2$ | Total pharyngeal airway minimum constricted area |

* ° (degree), % (ratio measurements), mm (millimeters), $mm^2$ (square millimeters), and $mm^3$ (cubic millimeters)

The descriptive analysis and statistical significance value for the skeletal, naso-, oro-, hypo-, and total pharyngeal airway space measurements are presented in Tables 5–9, respectively.

Table 6 shows there were statistical differences for nasopharyngeal measurements; the sagittal NP (A-P) mm and lateral NP (L-R) mm widths were the lowest in the skeletal Class III of 25.64 ± 3.10 mm and 36.64

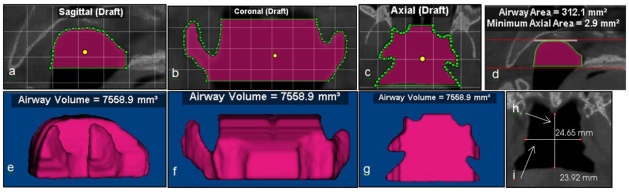


**Figure 2** Nasopharyngeal airway. (a) Surface area (sagittal view). (b) Surface area (coronal view). (c) Surface area (axial view). (d) Airway area (multiplanar view) and minimal constricted area. (e) Airway volume (sagittal view). (f) Airway volume (coronal view). (g) Airway volume (axial view). (h) Sagittal width of nasopharyngeal NP (A-P). (i) Lateral width of nasopharyngeal NP (L-R).

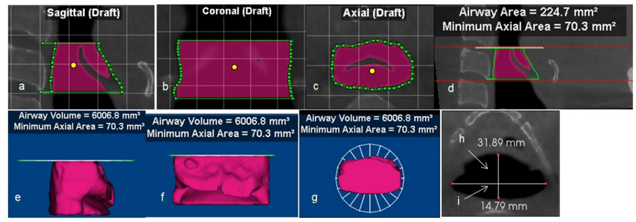


**Figure 4** Hypopharyngeal airway. (a) Surface area (sagittal view). (b) Surface area (coronal view). (c) Surface area (axial view). (d) Airway area and minimum constricted area (multiplanar view). (e) Airway volume (sagittal view). (f) Airway volume (coronal view). (g) Airway volume (axial view). (h) Sagittal width of hypopharyngeal OP (A-P). (i) Lateral width of hypopharyngeal OP (L-R).

± 5.49 mm respectively; the volumetric measurements NP-V mm³ and surface area NP-A mm² were the lowest in the hyperdivergent group of 6398.83 ± 1327.42 mm³,and 246.40 ± 44.16 mm³ respectively, and minimum constriction area MCA mm² was the highest in Class II and hypodivergent patients of 36.43 ± 17.57 mm² and 24.85 ± 13.43 mm² respectively.

Concerning the oropharyngeal measurements in Table 7, oropharyngeal sagittal width OP (A-P) mm, lateral width OP (L-R) mm, volume OP-V mm,³ surface area OP-A mm,² and minimum constriction area MCA mm² were significantly lower in the hyperdivergent patients than the relative's groups of, 12.12 ± 2.36 mm, 28.94 ± 4.95 mm, 14255.67 ± 3238.50 mm³, 517.87 ± 113.80 mm², and 49.06 ± 18.31 mm² respectively, and sagittal width OP (A-P) mm was significantly higher in patients with skeletal Class III malocclusion of 13.71 ± 2.93 mm.

For the statistically different hypopharyngeal measurements presented in Table 8, sagittal width HP (A-P) mm, volume HP-V mm³, surface area HP-A mm², and minimum constriction area MCA mm² were the lowest in the hyperdivergent patients of 14.86 ± 2.24 mm, 4813.95 ± 1239.28 mm³, 180.43 ± 33.25 mm² and 36.28 ± 16.32 mm² respectively, and lateral width was highest in skeletal Class III malocclusion of 33.42 ± 3.62 mm.

Table 9 showed there were statistically significant differences in total pharyngeal airway space volume TP-V mm³ and surface area TP-A mm²; both were lowest in the hyperdivergent group, 26003.60 ± 5343.68 mm³, and 944.36 ± 127.64 mm² respectively, and minimum constriction area MCA mm² was the lowest in the hyperdivergent and Class II patients of 42.60 ± 13.01 mm² and 41.13 ± 11.50 mm² repectively.

## Discussion

Breathing is based on the airway's anatomical dimensions. Several studies have shown that changes in skeletal patterns may predispose individuals to upper airway space obstruction.[34] Therefore, evaluating patients' airway dimensions among various sagittal/vertical craniofacial structures is critical to achieve orthodontic/orthognathic treatment objectives, esthetics, and function during treatment.

Previous studies are inconclusive regarding the effect of craniofacial patterns; thus, we aimed to improve field awareness by controlling for known variables. Many studies have reported that head posture influences airway size and morphology.[35] To decrease the impact of head posture, all patients' craniocervical inclinations were between 90° and 110°.[15,36]

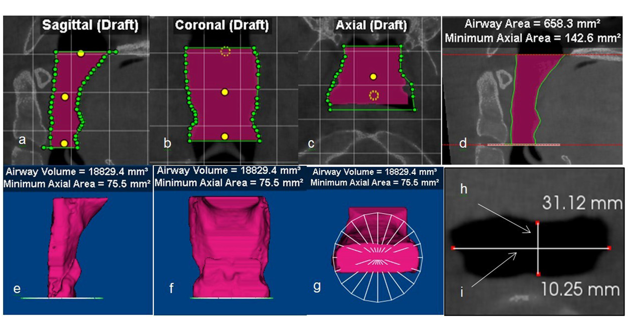


**Figure 3** Oropharyngeal airway. (a) Surface area (sagittal view). (b) Surface area (coronal view). (c) Surface area (axial view). (d) Airway area and minimum constricted area (multiplanar view). (e) Airway volume (sagittal view). (f) Airway volume (coronal view). (g) Airway volume (axial view). (h) Sagittal width of oropharyngeal OP (A-P). (i) Lateral width of oropharyngeal OP (L-R).

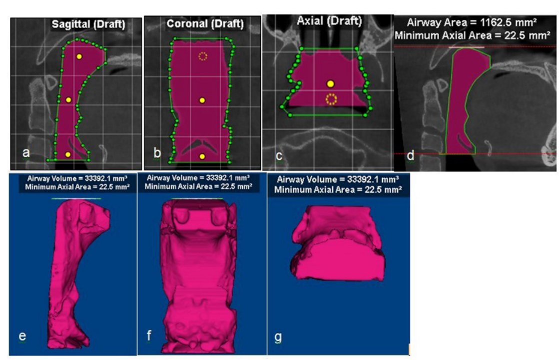


**Figure 5** Total pharyngeal airway (a) Surface area (sagittal view). (b) Surface area (coronal view). (c) Surface area (axial view). (d) Airway area and minimal constricted area (multiplanar view). (e) Airway volume (sagittal view). (f) Airway volume (coronal view). (g) Airway volume (axial view).

**Table 3** The study sample distribution among groups

| | | *Group I* | *Group II* | *Group III* | |
|---|---|---|---|---|---|
| | Facial growth | Class I<br>Mean ± SD | Class II<br>Mean ± SD | Class III<br>Mean ± SD | Total<br>Mean ± SD |
| Age | Hypodivergent | 24.03 ± 2.73<br>N=(42) | 24.15 ± 2.81<br>N=(40) | 22.86 ± 3.47<br>N=(40) | 23.69 ± 3.05<br>N=(122) |
| | Normodivergent | 23.35 ± 2.87<br>N=(42) | 23.96 ± 3.17<br>N=(41) | 23.26 ± 3.21<br>N=(41) | 23.52 ± 3.08<br>N=(124) |
| | Hyperdivergent | 24.53 ± 2.67<br>N=(40) | 24.06 ± 2.97<br>N=(42) | 25.23 ± 1.85<br>N=(40) | 24.60 ± 2.57<br>N=(122) |
| | Total | 23.96 ± 2.78<br>N=(124) | 24.05 ± 2.96<br>N=(123) | 23.78 ± 3.09<br>N=(121) | 23.93 ± 2.94<br>N=(368) |
| ANB° | Hypodivergent | 2.53 ± 1.08 | 6.11 ± 0.92 | −1.07 ± 1.57 | 2.52 ± 3.16 |
| | Normodivergent | 3.02 ± 0.96 | 6.12 ± 1.20 | −1.15 ± 1.72 | 2.67 ± 3.26 |
| | Hyperdivergent | 2.82 ± 0.85 | 6.10 ± 0.93 | −0.76 ± 1.40 | 2.78 ± 3.02 |
| | Total | 2.79 ± 0.98 | 6.11 ± 1.02 | −1.00 ± 1.56 | 2.65 ± 3.14 |
| AF-BF mm | Hypodivergent | 2.90 ± 1.52 | 7.62 ± 1.04 | −3.27 ± 2.60 | 2.43 ± 4.99 |
| | Normodivergent | 3.37 ± 1.47 | 8.26 ± 1.53 | −2.96 ± 2.70 | 2.89 ± 4.99 |
| | Hyperdivergent | 3.51 ± 1.47 | 8.40 ± 1.25 | −2.88 ± 2.46 | 3.10 ± 4.98 |
| | Total | 3.26 ± 1.50 | 8.10 ± 1.33 | −3.03 ± 2.57 | 2.81 ± 4.92 |
| GoGn-SN ° | Hypodivergent | 23.93 ± 2.43 | 26.45 ± 0.98 | 24.29 ± 0.98 | 24.88 ± 0.98 |
| | Normodivergent | 32.81 ± 2.17 | 32.85 ± 2.05 | 31.62 ± 2.15 | 32.43 ± 2.18 |
| | Hyperdivergent | 39.63 ± 1.64 | 40.07 ± 2.38 | 39.58 ± 2.18 | 39.76 ± 2.09 |
| | Total | 32.00 ± 6.77 | 33.23 ± 5.90 | 31.83 ± 6.60 | 32.36 ± 6.44 |
| | Hypodivergent | 72.52 ± 2.71 | 71.19 ± 1.51 | 71.84 ± 2.53 | 71.86 ± 2.36 |
| S-Go/N-Me % | Normodivergent | 65.64 ± 1.45 | 65.73 ± 1.34 | 65.58 ± 1.96 | 65.65 ± 1.59 |
| | Hyperdivergent | 59.64 ± 1.64 | 60.36 ± 1.52 | 60.43 ± 1.33 | 60.15 ± 1.54 |
| | Total | 66.04 ± 5.63 | 65.67 ± 4.67 | 65.95 ± 5.07 | 65.88 ± 5.13 |
| | Hypodivergent | 97.61 ± 4.64 | 99.85 ± 5.26 | 98.04 ± 5.55 | 98.48 ± 5.20 |
| OPT/SN ° | Normodivergent | 101.49 ± 6.11 | 100.335.35 | 97.50 ± 6.15 | 99.79 ± 6.07 |
| | Hyperdivergent | 102.06 ± 4.79 | 101.75 ± 4.49 | 99.16 ± 4.38 | 101.00 ± 4.70 |
| | Total | 100.36 ± 5.55 | 100.66 ± 5.06 | 98.23 ± 5.42 | 99.76 ± 5.44 |
| | Hypodivergent | 21.87 ± 2.52 | 22.53 ± 3.93 | 24.21 ± 2.68 | 22.85 ± 3.23 |
| BMI Kg/m2 | Normodivergent | 24.70 ± 2.29 | 25.20 ± 2.17 | 24.20 ± 1.97 | 24.70 ± 2.17 |
| | Hyperdivergent | 23.16 ± 1.87 | 23.97 ± 1.94 | 25.46 ± 2.29 | 24.19 ± 2.24 |
| | Total | 23.24 ± 2.52 | 23.91 ± 2.99 | 24.62 ± 2.38 | 23.92 ± 2.70 |

*SD: Standard deviation, N: Number of the subject, -°(degree), % (ratio measurements), mm (millimeters), $mm^2$ (square millimeters), $mm^3$ (cubic millimeters), and $Kg/m^2$ (kilograms per square meter).

In this study, skeletal Class III showed statistically smaller nasopharyngeal sagittal and lateral widths than skeletal Class III, which may manifest in skeletal Class III patients with a retruded and small maxilla, resulting in narrowing and decreasing of the nasopharyngeal airway dimensions. Also, we found that nasopharyngeal volume, surface area, and MCA were significantly smaller in the hyperdivergent group. This may be related to a patient with a hyperdivergent facial growth pattern having maxillary retrusion and decreased maxillary length and width.

According to Ucar et al,[7] the nasopharyngeal airway space in skeletal Class II subjects was larger in low-angle subjects than in high-angle subjects. A study by Joseph et al[5] noted that hyperdivergent subjects had a smaller sagittal pharyngeal dimension, particularly at the nasopharynx's hard palate level and the soft palate mandible tip level in the oropharynx, and this support the finding of this study. Another study by Memon et al[8] reported that smaller airway dimensions might be correlated with some skeletal features in hyperdivergent patients, such as maxillary and mandibular retrusion or vertical maxillary excess. The nasopharyngeal volume finding in this study is supported by Alhmmadi et al,[18] who showed no statistical significance in the volume between skeletal Class II and I; still, skeletal Class II was higher than skeletal Class I.

Gungor and Turkkahraman[37] evaluated the literature on the relationship between respiratory function and maxillary growth patterns and reported maxillary morphological differences between subjects with airway problems and control groups, indicating a possible etiological involvement of the airway in these subjects. Systematic review agree that maxillary expansion

**Table 4** Reliability analysis of all measurements used in this study.

| | *Intraobserver reliability* | | | | *Interobserver reliability* | | | |
|---|---|---|---|---|---|---|---|---|
| **Measurements** | **ICC** | **TEM** | **rTEM** | **R*** | **ICC** | **TEM** | **rTEM** | **R*** |
| ANB ° | 0.9955 | 0.2901 | 7.4146 | 0.9864 | 0.9906 | 0.3495 | 9.0526 | 0.9801 |
| AF-BF mm | 0.9968 | 0.3011 | 6.3786 | 0.9936 | 0.9985 | 0.2030 | 4.3124 | 0.9971 |
| GoGn- SN ° | 0.9982 | 0.2826 | 0.8750 | 0.9963 | 0.9977 | 0.3148 | 0.9749 | 0.9954 |
| SGo /NMe % | 0.9917 | 0.4665 | 0.7080 | 0.9829 | 0.9911 | 0.4787 | 0.7266 | 0.9820 |
| OP/SN° | 0.9956 | 0.4644 | 0.4627 | 0.9911 | 0.9953 | 0.4839 | 0.4821 | 0.9904 |
| SNA ° | 1.000 | 0.2210 | 0.2676 | 0.9939 | 0.9959 | 0.2578 | 0.3125 | 0.9914 |
| A-NV mm | 0.9937 | 0.1963 | 6.6903 | 0.9948 | 0.9962 | 0.2558 | 8.5279 | 0.9907 |
| Co-A mm | 0.9963 | 0.3253 | 0.3408 | 0.9920 | 0.9958 | 0.3336 | 0.3499 | 0.9916 |
| JL-JR mm | 0.9941 | 0.3540 | 0.5374 | 0.9863 | 0.9940 | 0.3291 | 0.5004 | 0.9882 |
| A-FH mm | 0.9922 | 0.3669 | 1.2013 | 0.9840 | 0.9918 | 0.3758 | 1.2305 | 0.9832 |
| SNB ° | 0.9970 | 0.2354 | 0.2992 | 0.9939 | 0.9970 | 0.2331 | 0.2965 | 0.9940 |
| B-NV mm | 0.9968 | 0.0823 | −4.642 | 0.9997 | 0.9982 | 0.1486 | −8.456 | 0.9989 |
| Gn-Go mm | 0.9880 | 0.6470 | 0.7581 | 0.9755 | 0.9877 | 0.6546 | 0.7671 | 0.9748 |
| Co-Gn mm | 0.9969 | 0.4249 | 0.3525 | 0.9926 | 0.9969 | 0.4190 | 0.3476 | 0.9928 |
| GoR-GoL mm | 0.9988 | 0.3535 | 0.3811 | 0.9967 | 0.9987 | 0.3578 | 0.3858 | 0.9967 |
| B-FH mm | 0.9904 | 0.7712 | 1.1030 | 0.9811 | 0.9904 | 0.7692 | 1.1003 | 0.9812 |
| NP (A-P) mm | 0.9991 | 0.2118 | 0.7584 | 0.9952 | 0.9975 | 0.2939 | 1.0516 | 0.9907 |
| NP (L-R) mm | 0.9988 | 0.2527 | 0.6519 | 0.9971 | 0.9954 | 0.4672 | 1.2048 | 0.9903 |
| NP-V $mm^3$ | 1.000 | 14.987 | 0.2178 | 0.9999 | 1.000 | 40.635 | 0.5914 | 0.9995 |
| NP-A $mm^2$ | 0.9970 | 5.3854 | 2.0787 | 0.9888 | 0.9923 | 6.8898 | 2.6518 | 0.9824 |
| NP-MCA $mm^2$ | 0.9795 | 3.4442 | 9.4880 | 0.9589 | 0.9797 | 3.9636 | 11.2225 | 0.9457 |
| OP (A-P) mm | 0.9949 | 0.3220 | 2.2246 | 0.9900 | 0.9942 | 0.3610 | 2.5106 | 0.9874 |
| OP (L-R) mm | 0.9977 | 0.4213 | 1.3291 | 0.9938 | 0.9968 | 0.4465 | 1.4111 | 0.9930 |
| OP-V $mm^3$ | 1.000 | 73.8340 | 0.4473 | 0.9998 | 0.9966 | 75.388 | 0.4569 | 0.9997 |
| OP-A $mm^2$ | 0.9984 | 6.1951 | 1.0837 | 0.9962 | 0.9984 | 6.7489 | 1.1787 | 0.9955 |
| OP-MCA $mm^2$ | 1.000 | 0.9865 | 1.6672 | 0.9984 | 1.000 | 0.7811 | 1.3247 | 0.9990 |
| HP(A-P)mm | 0.9965 | 0.2776 | 1.6498 | 0.9926 | 0.9966 | 0.2631 | 1.5594 | 0.9934 |
| HP(L-R)mm | 0.9973 | 0.3369 | 1.0349 | 0.9932 | 0.9979 | 0.2961 | 0.9100 | 0.9948 |
| HP-V $mm^3$ | 1.000 | 31.456 | 0.5152 | 0.9997 | 0.9998 | 38.839 | 0.6358 | 0.9996 |
| HP-A $mm^2$ | 0.9916 | 6.7736 | 3.1628 | 0.9817 | 0.9914 | 6.9822 | 3.2560 | 0.9806 |
| HP-MCA $mm^2$ | 1.000 | 1.0519 | 2.0442 | 0.9985 | 1.000 | 2.4561 | 4.6811 | 0.9918 |
| TP-V $mm^3$ | 1.000 | 79.360 | 0.2650 | 0.9998 | 0.9990 | 298.89 | 0.9996 | 0.9978 |
| TP-A $mm^2$ | 0.9967 | 12.9964 | 1.2606 | 0.9932 | 0.9956 | 14.5614 | 1.4094 | 0.9914 |
| TP-MCA $mm^2$ | 0.9865 | 2.6727 | 18.0851 | 0.9337 | 0.9728 | 0.3351 | 3.4967 | 0.9981 |

*ICC: Intraclass correlation coefficient TEM and rTEM indicate an absolute and relative technical error of measurement. °(degree), % (ratio measurements), mm (millemeters), $mm^2$ (square millemeters), $mm^3$ (cubic millimeters) and $Kg/m^2$ (kilograms per square meter).

can improve the nasal airway volume and obstructive sleeping apnea in both growing and non-growing patients in the short term. Maxillary expansion is one of the treatment options for patients with obstructive sleeping apnea.[38] As such, increasing maxillary width directly correlates to increased airway volume and functional improvement.[39]

This study showed that the oropharyngeal airway sagittal width, volume, surface area, and MCA were lower in the hyperdivergent group than in other groups. This result is related to most patients with hyperdivergent growth patterns having a component of mandibular deficiency and rotating downward and backward, thus decreasing the oropharyngeal airway dimensions.[3] This is in contrast to the hypodivergent group having a larger mandible body length and anticlockwise rotation than other groups. The oropharyngeal lateral widths were significantly higher in the skeletal Class III group. This is manifested in abnormal respiratory function being observed more frequently in skeletal Class II patients due to mandible deficiency.[40] This finding is consistent with Yanagita et al,[41] who reported oropharyngeal volume positively correlated with the mandibular body length and sagittal position of the mandible, and also supported by Hong et al,[42] who noted higher oropharyngeal airway dimensions in skeletal Class III patients than in skeletal Class I and II patients; however, this difference was not statistically significant. Similarly, several studies found a smaller oropharyngeal volume in subjects with skeletal Class II than skeletal Class I or skeletal Class III malocclusion.[11,19] Other studies had

**Table 5** Descriptive statistics and results of two-way ANOVA test for comparison between the offending jaw/s measurements of patients with different skeletal classes and facial growth patterns

| *Measurements* | *Facial growth* | *Class I Mean ± SD* | *Class II Mean ± SD* | *Class III Mean ± SD* | *Total Mean ± SD* | *Class* | *Facial growth* | *Class* Facial growth* |
|---|---|---|---|---|---|---|---|---|
| | Hypodivergent | 83.24 ± 2.07 | 84.21 ± 3.39 | 82.41 ± 2.57 | 83.28 ± 2.80[a] | | **0.000*** | 0.910 |
| SNA ° | Normodivergent | 81.80 ± 2.72 | 83.51 ± 2.79 | 81.51 ± 2.93 | 82.27 ± 2.93[b] | | | |
| | Hyperdivergent | 79.75 ± 2.37 | 81.39 ± 2.37 | 79.38 ± 2.86 | 80.19 ± 2.67[c] | | | |
| | Total | 81.63 ± 2.78[B] | 83.01 ± 3.09[A] | 81.10 ± 3.05[C] | 81.92 ± 3.07 | **0.000*** | | |
| | Hypodivergent | 3.40 ± 2.62 | 3.99 ± 2.74 | 1.71 ± 2.44 | 3.04 ± 2.76 | | 0.618 | 0.109 |
| A-NV mm | Normodivergent | 3.20 ± 2.55 | 4.06 ± 2.96 | 1.47 ± 2.69 | 2.91 ± 2.92 | | | |
| | Hyperdivergent | 2.19 ± 2.41 | 3.48 ± 1.90 | 2.43 ± 3.67 | 2.71 ± 2.78 | | | |
| | Total | 2.94 ± 2.56[B] | 3.84 ± 2.56[A] | 1.87 ± 2.98[C] | 2.89 ± 2.82 | **0.000*** | | |
| | Hypodivergent | 96.23 ± 3.96 | 97.16 ± 3.38 | 96.26 ± 3.95 | 96.54 ± 3.77[a] | | **0.000*** | 0.226 |
| Co-A mm | Normodivergent | 94.68 ± 3.32 | 96.81 ± 3.60 | 93.40 ± 4.72 | 94.96 ± 4.13[b] | | | |
| | Hyperdivergent | 93.26 ± 3.05 | 94.06 ± 3.22 | 92.56 ± 2.69 | 93.30 ± 3.04[c] | | | |
| . | Total | 94.75 ± 3.65[B] | 95.98 ± 3.65[A] | 94.07 ± 4.17[B] | 94.94 ± 3.90 | **0.000*** | | |
| | Hypodivergent | 66.40 ± 3.33 | 66.88 ± 2.95 | 65.80 ± 3.72 | 66.36 ± 3.35[a] | | **0.000*** | 0.117 |
| JR -JL mm | Normodivergent | 65.79 ± 3.23 | 66.63 ± 3.00 | 64.61 ± 2.42 | 65.68 ± 3.00[a] | | | |
| | Hyperdivergent | 64.77 ± 3.56 | 64.30 ± 2.37 | 64.81 ± 2.09 | 64.62 ± 2.73[b] | | | |
| | Total | 65.67 ± 3.41 | 65.91 ± 3.00 | 65.07 ± 2.85 | 65.55 ± 3.11 | 0.076 | | |
| | Hypodivergent | 29.61 ± 3.01 | 30.15 ± 3.46 | 29.87 ± 3.07 | 29.87 ± 3.17 | | 0.708 | 0.165 |
| A-FH mm | Normodivergent | 29.78 ± 2.85 | 31.33 ± 2.89 | 28.90 ± 2.44 | 30.00 ± 2.89 | | | |
| | Hyperdivergent | 29.75 ± 2.35 | 30.00 ± 2.64 | 29.33 ± 3.68 | 29.70 ± 2.93 | | | |
| | Total | 29.71 ± 2.74[A] | 30.49 ± 3.04[A] | 29.36 ± 3.10[B] | 29.86 ± 2.99 | **0.010*** | | |
| | Hypodivergent | 80.71 ± 2.37 | 78.10 ± 2.84 | 83.48 ± 2.83 | 80.76 ± 3.44[a] | | **0.000*** | 0.540 |
| SNB ° | Normodivergent | 78.78 ± 2.80 | 77.38 ± 2.58 | 82.66 ± 3.18 | 79.60 ± 3.62[b] | | | |
| | Hyperdivergent | 76.93 ± 2.27 | 75.29 ± 2.13 | 80.14 ± 2.92 | 77.42 ± 3.17[c] | | | |
| | Total | 78.84 ± 2.91[B] | 76.90 ± 2.78[C] | 82.10 ± 3.28[A] | 79.26 ± 3.68 | **0.000*** | | |
| | Hypodivergent | 0.69 ± 3.56 | −3.93 ± 3.14 | 5.04 ± 3.70 | 0.60 ± 5.02 | | 0.083 | 0.417 |
| B-NV mm | Normodivergent | −0.13 ± 3.46 | −4.28 ± 3.98 | 4.46 ± 3.82 | 0.02 ± 5.16 | | | |
| | Hyperdivergent | −1.32 ± 3.50 | −4.97 ± 2.63 | 5.02 ± 4.22 | −0.50 ± 5.41 | | | |
| | Total | −.23 ± 3.57[B] | −4.40 ± 3.30[C] | 4.84 ± 3.90[A] | 0.04 ± 5.20 | **0.000*** | | |
| | Hypodivergent | 94.25 ± 5.98 | 91.59 ± 4.12 | 94.23 ± 5.86 | 93.37 ± 5.50 | | 0.717 | **0.038*** |
| GoL-GoR mm | Normodivergent | 92.40 ± 6.67 | 93.79 ± 5.16 | 93.06 ± 5.08 | 93.08 ± 5.67 | | | |
| | Hyperdivergent | 93.14 ± 5.15 | 92.22 ± 4.37 | 95.53 ± 4.15 | 93.60 ± 4.75 | | | |
| | Total | 93.26 ± 5.98[B] | 92.54 ± 4.63[B] | 94.26 ± 5.14[A] | 93.35 ± 5.31 | **0.035*** | | |
| | Hypodivergent | 88.47 ± 3.76 | 82.92 ± 2.99 | 89.77 ± 4.14 | 87.08 ± 4.69[a] | | **0.000*** | **0.002*** |
| Gn-Go mm | Normodivergent | 85.71 ± 3.58 | 84.36 ± 4.63 | 87.3 ± 73.72 | 85.81 ± 4.15[b] | | | |
| | Hyperdivergent | 85.11 ± 3.45 | 82.55 ± 3.05 | 87.38 ± 3.41 | 84.97 ± 3.83[b] | | | |
| | Total | 86.45 ± 3.86[B] | 83.28 ± 3.70[C] | 88.17 ± 3.90[A] | 85.95 ± 4.31 | **0.000*** | | |
| | Hypodivergent | 121.82 ± 5.58 | 119.17 ± 4.48 | 125.44 ± 4.51 | 122.14 ± 5.49[a] | | **0.043*** | 0.650 |
| Gn-Co mm | Normodivergent | 121.11 ± 3.92 | 118.87 ± 5.79 | 123.13 ± 5.10 | 121.04 ± 5.25[a] | | | |
| | Hyperdivergent | 121.01 ± 3.75 | 117.86 ± 3.30 | 123.28 ± 4.63 | 120.67 ± 4.49[b] | | | |
| | Total | 121.32 ± 4.48[B] | 118.62 ± 4.62[C] | 123.94 ± 4.84[A] | 121.28 ± 5.12 | **0.000*** | | |
| | Hypodivergent | 65.82 ± 4.92 | 66.10 ± 4.20 | 65.94 ± 5.39 | 65.95 ± 4.82[c] | | **0.000*** | 0.426 |
| B-FH mm | Normodivergent | 69.41 ± 4.45 | 69.77 ± 4.28 | 68.46 ± 3.38 | 69.21 ± 4.07[b] | | | |
| | Hyperdivergent | 72.16 ± 4.73 | 71.63 ± 4.69 | 73.00 ± 4.13 | 72.25 ± 4.53[a] | | | |
| | Total | 69.08 ± 5.34 | 69.21 ± 4.93 | 69.13 ± 5.23 | 69.14 ± 5.16 | 0.997 | | |

*:Significant at $p \leq 0.05$
- ° (degree) and mm (millimeters)
A, B, C superscripts in the same row indicate statistically significant difference between classes, a, b, c superscripts in the same column indicate statistically significant difference between facial growth.

reported low or negligible correlations between craniofacial and oropharyngeal airway parameters.[12,19,21,42]

The present findings agreed with Palomo et al,[21] who measured the effective mandible length between the condylion and the mention, suggesting that mandible length contributes more to oropharynx size and volume than its position relative to the cranial base. This result was consistent with Trenouth and Timms,[43] who found that the oropharyngeal airway correlated positively with mandibular length. Mandibular width was related to

**Table 6** Descriptive statistics and results of two-way ANOVA test for comparison between the nasopharyngeal airway measurements of patients with different classes and facial growth patterns.

| *Measurements* | *Facial growth* | *Class I Mean ± SD* | *Class II Mean ± SD* | *Class III Mean ± SD* | *Total Mean ± SD* | *Class* | *Facial growth* | *Class* Facial growth* |
|---|---|---|---|---|---|---|---|---|
| NP (A-P) mm | Hypodivergent | 28.11 ± 3.56 | 27.60 ± 3.82 | 26.69 ± 2.73 | 27.48 ± 3.43[a] | | **0.028*** | 0.238 |
| | Normodivergent | 28.16 ± 2.47 | 28.33 ± 3.26 | 25.64 ± 3.29 | 27.38 ± 3.24[a] | | | |
| | Hyperdivergent | 26.99 ± 2.85 | 27.96 ± 2.19 | 24.60 ± 2.98 | 26.54 ± 3.02[b] | | | |
| | Total | 27.77 ± 3.02[A] | 27.97 ± 3.14[A] | 25.64 ± 3.10[B] | 27.14 ± 3.25 | **0.000*** | | |
| NP (L-R) mm | Hypodivergent | 38.40 ± 6.29 | 36.42 ± 3.41 | 36.98 ± 5.05 | 37.28 ± 5.11 | | 0.145 | 0.092 |
| | Normodivergent | 38.73 ± 3.91 | 39.28 ± 4.27 | 37.41 ± 5.52 | 38.48 ± 4.65 | | | |
| | Hyperdivergent | 38.83 ± 4.95 | 38.89 ± 3.45 | 35.51 ± 5.83 | 37.76 ± 5.04 | | | |
| | Total | 38.65 ± 5.11[A] | 38.22 ± 3.91[A] | 36.64 ± 5.49[B] | 37.84 ± 4.95 | **0.003*** | | |
| NP-V mm³ | Hypodivergent | 7617.50 ± 1589.27 | 7230.92 ± 1555.83 | 7514.32 ± 1597.14 | 7456.92 ± 1576.43[a] | | **0.000*** | 0.232 |
| | Normodivergent | 7029.29 ± 1855.22 | 7511.88 ± 1909.81 | 7013.87 ± 1979.70 | 7183.76 ± 1913.54[a] | | | |
| | Hyperdivergent | 6204.74 ± 1369.09 | 6809.61 ± 1352.10 | 6161.62 ± 1180.04 | 6398.83 ± 1327.42[b] | | | |
| | Total | 6962.54 ± 1708.30 | 7180.71 ± 1633.75 | 6897.57 ± 1702.93 | 7014.10 ± 1681.74 | 0.338 | | |
| NP-A mm² | Hypodivergent | 290.33 ± 59.99 | 254.12 ± 51.98 | 275.28 ± 53.00 | 273.52 ± 56.74[a] | | **0.001*** | **0.006*** |
| | Normodivergent | 261.55 ± 62.39 | 281.07 ± 67.09 | 256.25 ± 67.86 | 266.25 ± 66.13[a] | | | |
| | Hyperdivergent | 239.62 ± 46.42 | 258.04 ± 45.98 | 240.97 ± 38.08 | 246.40 ± 44.16[b] | | | |
| | Total | 264.22 ± 60.10 | 264.44 ± 56.50 | 257.49 ± 55.83 | 262.08 ± 57.45 | 0.562 | | |
| NP-MCA mm² | Hypodivergent | 33.50 ± 15.89 | 48.69 ± 15.69 | 38.60 ± 18.00 | 40.15 ± 17.64[a] | | **0.000*** | **0.011*** |
| | Normodivergent | 30.99 ± 14.52 | 33.57 ± 14.21 | 39.81 ± 17.47 | 34.21 ± 15.72[b] | | | |
| | Hyperdivergent | 23.38 ± 12.91 | 27.53 ± 15.69 | 23.49 ± 11.05 | 24.85 ± 13.43[c] | | | |
| | Total | 29.39 ± 15.02[B] | 36.43±17.57**A** | 33.45±17.30**A** | 33.08 ± 16.84 | **0.001*** | | |

*Significant at $p \leq 0.05$
-mm (millimeters), mm² (square millimeters), and mm³ (cubic millimeters)
A, B, C superscripts in the same row indicate statistically significant difference between classes, a, b, c superscripts in the same column indicate statistically significant difference between facial growth.

the dimensions of the oropharyngeal. This finding is consistent with Nejaim et al,[17] who reported a positive correlation between mandibular width and oropharyngeal volume.

The current study considered more in skeletal Class II and III than in skeletal Class I malocclusion; this consideration is more important in patients undergoing mandibular surgery because more negative/positive changes in the pharyngeal airway space dimensions may occur. Because the mandible is associated with the hyoid bone, tongue, and soft palate by muscles, any movement in the mandible can affect the size of the airway space.

**Table 7** Descriptive statistics and results of two-way ANOVA test for comparison between the oropharyngeal airway measurements of patients with different skeletal classes and facial growth patterns

| *Measurements* | *Facial growth* | *Class I Mean ± SD* | *Class II Mean ± SD* | *Class III Mean ± SD* | *Total Mean ± SD* | *Class* | *Facial growth* | *Class*facial growth* |
|---|---|---|---|---|---|---|---|---|
| OP (A-P) mm | Hypodivergent | 13.68 ± 2.95 | 13.23 ± 3.65 | 14.49 ± 2.84 | 13.80 ± 3.18[a] | | **0.000*** | 0.898 |
| | Normodivergent | 14.10 ± 3.26 | 13.31 ± 2.73 | 14.24 ± 3.28 | 13.88 ± 3.10[a] | | | |
| | Hyperdivergent | 12.49 ± 2.72 | 11.49 ± 2.08 | 12.40 ± 2.17 | 12.12 ± 2.36[b] | | | |
| | Total | 13.44 ± 3.04[A] | 12.66 ± 2.98[B] | 13.71 ± 2.93[A] | 13.27 ± 3.01 | **0.016*** | | |
| OP (L-R) mm | Hypodivergent | 31.07 ± 5.42 | 30.98 ± 3.95 | 31.11 ± 5.68 | 31.05 ± 5.04[a] | | **0.000*** | 0.580 |
| | Normodivergent | 31.33 ± 4.63 | 31.63 ± 3.78 | 30.63 ± 4.52 | 31.20 ± 4.31[a] | | | |
| | Hyperdivergent | 29.41 ± 5.05 | 28.03 ± 5.00 | 29.43 ± 4.77 | 28.94 ± 4.95[b] | | | |
| | Total | 30.62 ± 5.07 | 30.19 ± 4.54 | 30.40 ± 5.02 | 30.40 ± 4.87 | 0.813 | | |
| OP-V mm³ | Hypodivergent | 15318.02 ± 3888.89 | 15415.82 ± 3357.97 | 15683.99 ± 4324.78 | 15470.08 ± 3848.57[a] | | **0.008*** | 0.969 |
| | Normodivergent | 15548.48 ± 4232.78 | 15307.62 ± 3805.97 | 16097.33 ± 4235.44 | 15650.32 ± 4077.49[a] | | | |
| | Hyperdivergent | 14476.87 ± 3876.62 | 13846.26 ± 2845.39 | 14464.34 ± 2953.69 | 14255.67 ± 3238.50[b] | | | |
| | Total | 15124.74 ± 3998.61 | 14843.81 ± 3405.43 | 15420.86 ± 3921.50 | 15128.21 ± 3781.19 | 0.510 | | |
| OP-A mm² | Hypodivergent | 556.79 ± 104.68 | 558.82 ± 102.73 | 561.64 ± 102.56 | 559.05 ± 102.51[a] | | **0.004*** | 0.467 |
| | Normodivergent | 555.42 ± 100.39 | 557.74 ± 97.20 | 550.59 ± 96.50 | 554.59 ± 97.31[a] | | | |
| | Hyperdivergent | 537.29 ± 97.15 | 489.90 ± 144.55 | 527.83 ± 86.27 | 517.87 ± 113.80[b] | | | |
| | Total | 550.03 ± 100.41 | 534.93 ± 120.64 | 546.72 ± 95.60 | 543.90 ± 106.06 | 0.530 | | |
| OP-MCA mm² | Hypodivergent | 61.86 ± 33.57 | 59.93 ± 21.69 | 62.41 ± 16.58 | 61.41 ± 24.96[a] | | **0.000*** | 0.955 |
| | Normodivergent | 59.46 ± 26.46 | 61.10 ± 18.88 | 60.95 ± 27.43 | 60.50 ± 24.39[a] | | | |
| | Hyperdivergent | 48.89 ± 21.93 | 46.65 ± 18.66 | 51.74 ± 13.39 | 49.06 ± 18.31[b] | | | |
| | Total | 56.86 ± 28.16 | 55.79 ± 20.69 | 58.39 ± 20.51 | 57.01 ± 23.38 | 0.693 | | |

*Significant at $p \leq 0.05$
-mm (millimeters), mm² (square millimeters), and mm³ (cubic millimeters)
A, B, C superscripts in the same row indicate statistically significant difference between classes, a, b, c superscripts in the same column indicate statistically significant difference between facial growth

**Table 8** Descriptive statistics and results of two-way ANOVA test for comparison between the hypopharyngeal airway measurements of patients with different skeletal classes and facial growth patterns

| *Measurements* | *Facial growth* | *Class I Mean ± SD* | *Class II Mean ± SD* | *Class III Mean ± SD* | *Total Mean ± SD* | *Class* | *Facial growth* | *Class*facial growth* |
|---|---|---|---|---|---|---|---|---|
| HP (A-P) mm | Hypodivergent | 16.00 ± 2.95 | 15.85 ± 2.50 | 16.56 ± 3.43 | 16.14 ± 2.97[a] | | **0.001*** | 0.349 |
| | Normodivergent | 15.83 ± 2.56 | 15.49 ± 2.96 | 16.36 ± 3.59 | 15.89 ± 3.06[a] | | | |
| | Hyperdivergent | 15.58 ± 2.09 | 14.48 ± 2.23 | 14.54 ± 2.26 | 14.86 ± 2.24[b] | | | |
| | Total | 15.81 ± 2.55 | 15.26 ± 2.63 | 15.82 ± 3.26 | 15.63 ± 2.83 | 0.215 | | |
| HP (L-R) mm | Hypodivergent | 32.91 ± 3.68 | 31.43 ± 2.53 | 33.08 ± 5.32 | 32.48 ± 4.04 | | 0.405 | **0.000*** |
| | Normodivergent | 32.19 ± 3.40 | 34.02 ± 2.64 | 32.87 ± 2.69 | 33.02 ± 3.01 | | | |
| | Hyperdivergent | 30.78 ± 2.74 | 33.08 ± 3.03 | 34.31 ± 1.83 | 32.73 ± 2.95 | | | |
| | Total | 31.98 ± 3.39[B] | 32.86 ± 2.93[A] | 33.42 ± 3.62[A] | 32.75 ± 3.37 | **0.002*** | | |
| HP-V mm³ | Hypodivergent | 6008.64 ± 1364.34 | 5499.98 ± 1520.04 | 6142.57 ± 1742.64 | 5885.77 ± 1559.00[a] | | **0.000*** | 0.763 |
| | Normodivergent | 5881.24 ± 1831.07 | 5889.05 ± 1489.70 | 5929.79 ± 2091.19 | 5899.88 ± 1806.07[a] | | | |
| | Hyperdivergent | 4935.37 ± 1396.33 | 4586.18 ± 1099.62 | 4931.69 ± 1207.82 | 4813.95 ± 1239.28[b] | | | |
| | Total | 5619.27 ± 1607.36 | 5317.64 ± 1475.60 | 5670.18 ± 1788.29 | 5535.19 ± 1630.84 | 0.184 | | |
| HP-A mm² | Hypodivergent | 220.61 ± 45.97 | 194.29 ± 45.39 | 221.50 ± 42.39 | 212.27 ± 46.03[a] | | **0.000*** | 0.462 |
| | Normodivergent | 209.65 ± 46.18 | 204.22 ± 46.76 | 212.41 ± 53.19 | 208.77 ± 48.51[a] | | | |
| | Hyperdivergent | 182.91 ± 38.03 | 174.69 ± 31.23 | 183.99 ± 30.08 | 180.43 ± 33.25[b] | | | |
| | Total | 204.74 ± 46.08[a] | 190.91 ± 43.09[b] | 206.02 ± 45.57[a] | 200.54 ± 45.33 | **0.012*** | | |
| HP-MCA mm² | Hypodivergent | 48.14 ± 24.45 | 43.48 ± 21.29 | 47.20 ± 17.67 | 46.30 ± 21.29[a] | | **0.000*** | 0.599 |
| | Normodivergent | 50.27 ± 21.03 | 50.33 ± 27.59 | 48.67 ± 20.23 | 49.76 ± 22.99[a] | | | |
| | Hyperdivergent | 34.52 ± 13.97 | 33.85 ± 17.86 | 40.60 ± 16.34 | 36.28 ± 16.32[b] | | | |
| | Total | 44.46 ± 21.37 | 42.47 ± 23.42 | 45.51 ± 18.36 | 44.14 ± 21.15 | 0.530 | | |

*Significant at $p \leq 0.05$
-mm (millimeters), mm² (square millimeters), and mm³ (cubic millimeters)
A, B, C superscripts in the same row indicate statistically significant difference between classes, a, b, c superscripts in the same column indicate statistically significant difference between facial growth.

This current study showed smaller statistical significance in the hypopharyngeal airway sagittal width, volume, surface area, and MCA in the hyperdivergent group and a statistically significant difference in lateral width with a higher value in the Class III group. The patients with skeletal Class II and hyperdivergent growth patterns exhibited a retruding mandible and verse versa in Class III, which means the sagittal position of the mandible affects the hypopharyngeal airway. Thus, we need to take into account control of the mandibular position during the manipulation of the jaws because any movement is accompanied by a change in position of the hyoid bone. This is clearly explained by Jiang et al,[44] who concluded that hyoid bone moved superiorly

**Table 9** Descriptive statistics and results of two-way ANOVA test for comparison between the total pharyngeal airway measurements of patients with different skeletal classes and facial growth patterns

| *Measurements* | *Facial growth* | *Class I Mean ± SD* | *Class II Mean ± SD* | *Class III Mean ± SD* | *Total Mean ± SD* | *Class* | *Facial growth* | *Class*Facial growth* |
|---|---|---|---|---|---|---|---|---|
| TP-V mm³ | Hypodivergent | 29567.53 ± 6540.35 | 28188.31 ± 5268.73 | 29595.60 ± 7205.71 | 29124.53 ± 6372.45[a] | | **0.000*** | 0.684 |
| | Normodivergent | 29341.18 ± 6286.89 | 29669.52 ± 5289.99 | 28402.72 ± 7135.84 | 29139.45 ± 6254.87[a] | | | |
| | Hyperdivergent | 26370.76 ± 6701.32 | 25406.26 ± 3445.08 | 26263.66 ± 5533.25 | 26003.60 ± 5343.68[b] | | | |
| | Total | 28459.65 ± 6616.36 | 27732.08 ± 5022.91 | 28089.93 ± 6760.14 | 28094.90 ± 6171.73 | 0.682 | | |
| TP-A mm² | Hypodivergent | 1058.52 ± 161.24 | 1001.39 ± 136.95 | 1066.73 ± 179.96 | 1042.48 ± 161.66[a] | | **0.000*** | 0.437 |
| | Normodivergent | 1031.99 ± 146.78 | 1036.76 ± 166.36 | 1012.92 ± 173.10 | 1027.26 ± 161.34[a] | | | |
| | Hyperdivergent | 948.48 ± 159.96 | 930.98 ± 98.41 | 954.28 ± 120.29 | 944.36 ± 127.64[b] | | | |
| | Total | 1014.04 ± 161.69 | 989.14 ± 142.48 | 1011.33 ± 165.30 | 1004.82 ± 156.75 | 0.405 | | |
| TP-MCA mm² | Hypodivergent | 47.72 ± 16.19 | 50.57 ± 13.39 | 53.31 ± 21.90 | 50.49 ± 17.50[a] | | **0.000*** | 0.238 |
| | Normodivergent | 44.41 ± 12.08 | 41.38 ± 11.88 | 52.25 ± 14.04 | 46.00 ± 13.40[a] | | | |
| | Hyperdivergent | 41.48 ± 12.31 | 36.20 ± 9.49 | 45.94 ± 10.66 | 41.13 ± 11.50[b] | | | |
| | Total | 44.59 ± 13.80[B] | 42.60 ± 13.01[B] | 50.52 ± 16.40[A] | 45.87 ± 14.81 | **0.000*** | | |

*Significant at $p \leq 0.05$
-mm (millimeters), mm² (square millimeters), and mm³ (cubic millimeters)
A, B, C superscripts in the same row indicate statistically significant difference between classes, a, b, c superscripts in the same column indicate statistically significant difference between facial growth.

and forward in the mandibular advancement group, causing the widening of the hypopharyngeal airway.

The total pharyngeal volume, surface area, and MCA were the smallest statistically significant in hyperdivergent patients; MCA was the smallest statistically significant in skeletal Class II patients. This is supported by Abbas Shokri et al,[45] who found the anteroposterior jaws relation influences airway measurements. In general, this effect should be considered during orthognathic surgery; specifically, in the mandibular setback or advancement surgery in skeletal Class III or II malocclusion patients. These procedures can cause negative or positive alterations in the pharyngeal airway.

In summary, according to the present study's findings, comparing the pharyngeal airway space in patients with normal nasal breathing revealed a significant difference between different craniofacial growth patterns.

## Conclusion

Based on this study's findings, the following could be concluded:

(1) Skeletal Class II malocclusion was significantly associated with greater nasopharyngeal sagittal width and MCA, and hypodivergent patients had a significantly greater nasopharyngeal volume, surface area, and MCA.
(2) The hyperdivergent patients had a significantly smaller oropharyngeal sagittal width, volume, surface area, and MCA, and skeletal Class III had the greatest sagittal width.
(3) The hyperdivergent patients had a significantly smaller hypopharyngeal sagittal width, volume, surface area, and MCA, and skeletal Class III had the greatest lateral width.
(4) The hyperdivergent group had the smallest total pharyngeal airway volume, surface area, and MCA significantly; skeletal Class II patients had the lowest MCA.

Generally, the knowledge of pharyngeal airway differences caused by sagittal and vertical could help diagnose pharyngeal airway pathologies and be considered during clinical diagnosis and planning for craniofacial orthopedics and orthognathic surgical treatment.

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## Competing interests

The authors declare any conflicts of interest.

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## Consent for publication

Not applicable.

## Ethics approval and consent to participate

The ethical committee of clinical scientific research of the school of stomatology of Lanzhou University approved this study (No: LZUKQ-2019-056). Moreover, every participant provided their informed consent.

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