

“Comparative Evaluation of Airway Dimensions in Different Sagittal and Vertical Skeletal Patterns: A Two-Dimensional Cephalometric Study from Central India”

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ABSTRACT

Background: Pharyngeal airway dimensions are influenced by craniofacial morphology and skeletal growth patterns. Variations in sagittal skeletal relationships and vertical growth patterns may affect the dimensions of the upper and lower pharyngeal airway. Understanding these associations may provide useful information for orthodontic diagnosis and treatment planning.

Aim: To evaluate and compare upper and lower pharyngeal airway widths among different vertical growth patterns in skeletal Class I, Class II, and Class III subjects.

Materials and Methods: The study included 150 subjects distributed equally among skeletal Class I, Class II, and Class III groups, with 50 subjects in each skeletal class. Each skeletal class was further categorized according to vertical growth pattern into hypodivergent, normodivergent, and hyperdivergent groups. Upper and lower pharyngeal widths were assessed using lateral cephalometric measurements. The mean values and standard deviations were calculated for each subgroup, and comparisons were performed between growth patterns and among skeletal classes. Pairwise comparisons were used to determine differences between individual skeletal groups. **Results:** Upper pharyngeal width showed a progressive reduction from hypodivergent to hyperdivergent growth patterns in all three skeletal classes. In skeletal Class I, the mean upper pharyngeal width was 12.563 mm in hypodivergent, 10.494 mm in normodivergent, and 9.583 mm in hyperdivergent subjects. Corresponding values for Class II were 11.762, 9.981, and 8.344 mm, while Class III showed values of 15.737, 14.962, and 14.366 mm, respectively. A similar pattern was observed for lower pharyngeal width. The overall mean upper pharyngeal widths were 10.82 mm, 9.96 mm, and 14.99 mm for Classes I, II, and III, respectively. For lower pharyngeal width, the corresponding means were 10.49 mm, 7.25 mm, and 14.12 mm. Pairwise analysis demonstrated statistically significant differences among the skeletal classes for both upper and lower pharyngeal widths.

Conclusion: Pharyngeal airway dimensions varied significantly according to skeletal classification and vertical growth pattern. Hypodivergent subjects generally demonstrated greater pharyngeal widths than hyperdivergent subjects, while skeletal Class III subjects exhibited the greatest upper and lower pharyngeal dimensions. These findings highlight the relevance of skeletal morphology and vertical growth pattern in the assessment of pharyngeal airway dimensions during orthodontic diagnosis and treatment planning.

Keywords: Pharyngeal airway; skeletal malocclusion; vertical growth pattern; Hypodivergent; Hyperdivergent; Cephalometry.

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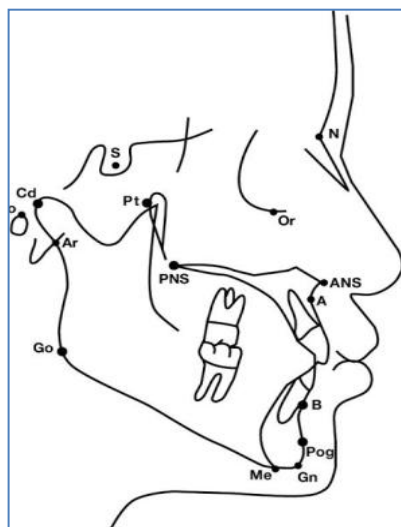
INTRODUCTION

Orthodontics is a specialized branch of dentistry that focuses on the identification, prevention, and correction of malocclusion and associated craniofacial abnormalities. The field primarily deals with the development and morphology of the craniofacial complex, with particular attention to dentoalveolar structures and their relationship with the underlying skeletal framework.¹ The effectiveness of orthodontic treatment depends greatly on an accurate diagnosis and a systematic treatment plan. Diagnostic evaluation generally includes a detailed clinical examination, medical and dental history, study casts or digital models, and appropriate radiographic investigations. Among these diagnostic aids, cephalometric radiography has remained an important method for evaluating craniofacial relationships and documenting skeletal and dental changes associated with orthodontic treatment. Cephalometric assessment is commonly performed on standardized lateral radiographs obtained using a cephalostat, allowing quantitative evaluation of skeletal, dental, and soft-tissue relationships. Although cephalometric examination is not essential for every orthodontic patient, it is particularly useful when substantial anteroposterior repositioning of the dentition is expected, especially when significant changes in incisor inclination or position are planned.

The development of cephalometric radiography can be traced to the early application of radiographs for evaluating craniofacial structures in the late nineteenth

century. A major advancement occurred during the 1930s with the work of Broadbent, who established a standardized method for obtaining cephalometric radiographs and introduced systematic assessment of dental and skeletal relationships using angular and linear measurements.² subsequently; several analytical approaches were developed to improve the interpretation of sagittal and vertical skeletal discrepancies. Among these, the Wits appraisal became an important complementary method for evaluating anteroposterior jaw relationships. These developments established cephalometric analysis as an integral component of orthodontic diagnosis, treatment planning, and assessment of treatment-related changes.

Cephalometric evaluation involves assessment of the spatial relationships of the maxilla and mandible with the cranial base as well as with the dentition. Both sagittal and vertical components of craniofacial morphology can be quantified through a combination of angular and linear measurements (Fig. 1). The obtained values are generally compared with established normative data derived from specific populations. Analysis may be performed manually or with computer-assisted systems. Nevertheless, interpretation can be affected by factors such as radiographic magnification, projection-related distortion, landmark identification errors, and examiner variability. Therefore, cephalometric measurements should not be interpreted independently and must be integrated with clinical findings and other diagnostic information.²



(Fig. 1)

STANDARDIZED LATERAL CEPHALOMETRIC RADIOGRAPHS

Lateral cephalometric radiography provides a standardized two-dimensional representation of the craniofacial structures and is particularly useful for

evaluating sagittal and vertical skeletal relationships. Sagittal assessment provides information regarding the anteroposterior position of the maxilla and mandible, whereas vertical analysis helps determine facial height proportions and growth direction. Posteroanterior cephalograms can provide additional information regarding transverse skeletal relationships; however, their interpretation is comparatively demanding and therefore their routine clinical application is less frequent.³

Reproducibility of cephalometric measurements depends substantially on standardized radiographic acquisition. During exposure, the patient should be positioned with the Frankfort horizontal plane appropriately oriented, the teeth maintained in centric occlusion, and the head stabilized through ear rods positioned within the external auditory meatus. Proper alignment of the nasion and maintenance of a consistent relationship between the midsagittal plane and the radiation source are also necessary. Incorporation of a calibrated scale or ruler during radiographic acquisition can assist in minimizing errors associated with magnification and improve the reliability of linear measurements.³

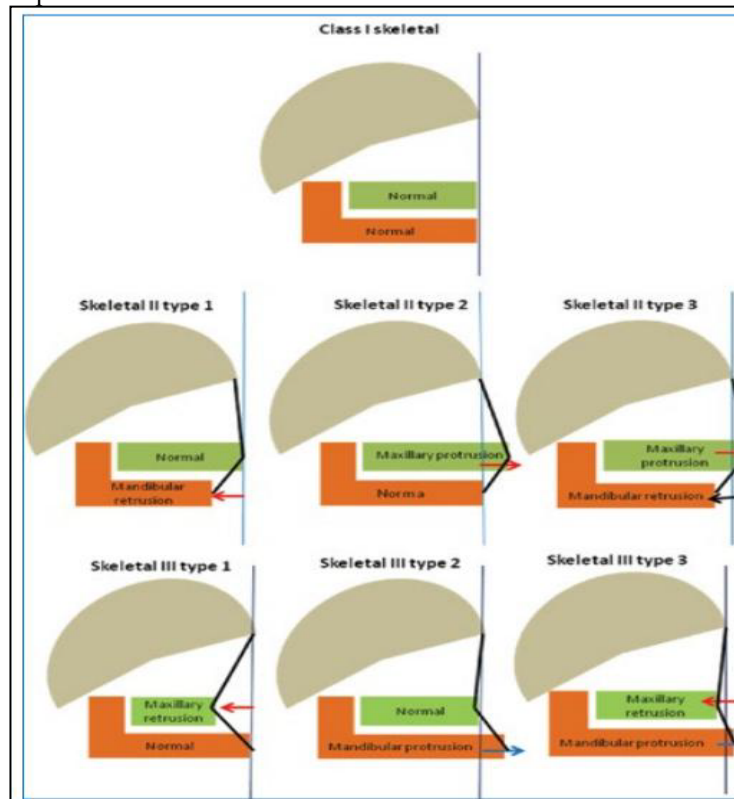
The concept of relating dental structures to the craniofacial skeleton was further developed by Simon in 1930. He proposed the use of three principal reference planes—the Frankfort horizontal plane, orbital plane, and vertical plane of attraction—to describe the spatial position of the dental arches in

relation to the craniofacial complex. He additionally described the median sagittal plane and evaluated craniofacial relationships in anteroposterior and transverse dimensions.⁴

SKELETAL CLASSIFICATION (Fig. 2)

Skeletal facial patterns can be broadly categorized according to the sagittal relationship between the maxilla and mandible. Salzmann classified skeletal patterns into Class I, characterized by a relatively straight profile; Class II, associated with a convex profile; and Class III, generally characterized by a concave profile.⁵ However, this descriptive classification does not establish whether the underlying discrepancy originates primarily from the maxilla, mandible, or both.

A skeletal Class I pattern represents a relatively balanced anteroposterior relationship between the maxilla and mandible, although minor skeletal or dental variations may be present. In contrast, a Class II skeletal relationship may result from mandibular retrusion, maxillary advancement or protrusion, or a combination of both components. Similarly, a Class III relationship may develop because of maxillary deficiency, mandibular prognathism, or the simultaneous presence of both maxillary and mandibular components.⁵ Identification of the specific skeletal component involved is essential for selecting an appropriate treatment approach and predicting the response to orthodontic or orthopedic intervention.



(Fig.2) Skeletal Pattern

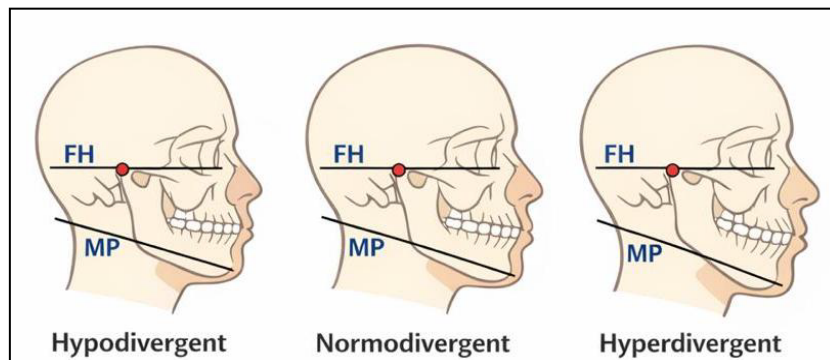
ANTEROPOSTERIOR AND VERTICAL SKELETAL ASSESSMENT (Fig. 3)

The sagittal position of the maxilla relative to the anterior cranial base is commonly evaluated using the SNA angle. The conventional mean value is approximately 82° . An increase in the SNA measurement generally suggests a relatively forward-positioned maxilla, whereas a reduced value may indicate maxillary retrusion. The SNB angle is used to assess the anteroposterior position of the mandible and has an accepted average value of approximately 80° . Higher SNB values are generally associated with mandibular prognathism, while lower values suggest mandibular retrusion.

The relationship between the maxilla and mandible can be further assessed using the ANB angle, which is calculated from the difference between SNA and SNB. An ANB value of approximately 2° is traditionally

considered indicative of a skeletal Class I relationship. Values exceeding this range generally suggest a Class II skeletal relationship, whereas reduced or negative values are commonly associated with Class III patterns. However, ANB is influenced by factors such as cranial base morphology, facial divergence, and the relative position of the nasion. Consequently, it should not be interpreted in isolation, and complementary measurements such as the Wits appraisal may provide additional information regarding sagittal jaw discrepancies.⁶

Vertical skeletal relationships can be evaluated using measurements such as the mandibular plane to anterior cranial base angle (M/SN) and the mandibular plane to palatal plane angle (M/SpP). These parameters assist in identifying the predominant facial growth pattern and allow individuals to be broadly categorized as hypodivergent, normodivergent, or hyperdivergent.⁷



(Fig.3)-Hypodivergent, Normodivergent and Hyperdivergent-based on the inclination of mandibular plane relative to the Frankfort horizontal plane.

CEPHALOMETRIC EVALUATION OF THE UPPER AIRWAY

The upper airway consists principally of the nasopharyngeal, oropharyngeal, and hypopharyngeal regions and has an important role in respiration and swallowing. Alterations in airway dimensions may be associated with changes in respiratory function and craniofacial development. In particular, compromised airway space may contribute to mouth breathing and adaptive changes in head, jaw, and tongue posture. Solow's soft-tissue stretching hypothesis proposes that changes in respiratory function may influence head posture and subsequently modify mandibular and tongue positioning, potentially affecting craniofacial growth.⁸

The hyoid bone is another important anatomical structure associated with airway maintenance and craniofacial posture. Its position is influenced by mandibular movement, tongue posture, and the surrounding musculature. Alterations in mandibular position may consequently be accompanied by changes in hyoid position and airway dimensions.

Several investigations have demonstrated an association between craniofacial morphology and airway characteristics, particularly with respect to mandibular length and the dimensions of the oropharyngeal airway. Lateral cephalometric radiographs can provide clinically useful estimates of nasopharyngeal and retropalatal airway dimensions.⁹ Reduced airway dimensions have been reported in association with mouth breathing, altered skeletal growth patterns, and sleep-related breathing abnormalities. Individuals with skeletal Class II patterns frequently demonstrate comparatively restricted airway dimensions, whereas Class III subjects may exhibit relatively greater airway space.¹⁰

Although three-dimensional techniques, particularly cone-beam computed tomography (CBCT), permit detailed visualization of the airway, their routine application is restricted by factors such as radiation exposure, financial cost, and availability. For this reason, lateral cephalometry continues to represent a practical and accessible method for preliminary airway assessment in orthodontic patients.

DIGITAL CEPHALOMETRIC ANALYSIS

The introduction of computerized cephalometric systems has considerably improved the efficiency of cephalometric analysis. Software platforms such as NemoCeph, incorporated within NemoStudio, facilitate digital landmark identification, automated measurements, and rapid generation of cephalometric analyses. These systems can integrate anthropometric

information with predictive models and may also permit visualization and simulation of anticipated treatment outcomes, including orthodontic and surgical treatment objectives.¹¹

Despite these advantages, digital analysis remains dependent on the quality and standardization of the radiographic image, accurate landmark identification, and the suitability of the reference norms applied to the patient population. Consequently, computerized measurements should be interpreted in conjunction with clinical findings rather than being considered independently. Manual tracing continues to have educational and clinical relevance; however, it is relatively time-consuming and may demonstrate examiner-dependent variability and landmark identification errors. Digital approaches can reduce processing time, improve measurement reproducibility, facilitate standardized data collection, and allow efficient analysis of large datasets.¹¹ These advantages have contributed to their increasing application in contemporary orthodontic diagnosis and research.

POPULATION-SPECIFIC CEPHALOMETRIC CONSIDERATIONS

Cephalometric parameters demonstrate considerable variation among different ethnic and geographic populations. Studies involving Central Indian populations have identified craniofacial characteristics that differ from commonly used Caucasian reference standards, including variations in mandibular dimensions, incisor inclination, and chin prominence.¹² A tendency toward bimaxillary dentoalveolar protrusion, accompanied by increased proclination of the incisors despite comparatively balanced skeletal bases, has also been reported among Indian subjects.¹³ Such characteristics may have important implications for extraction decisions, incisor positioning, facial aesthetics, and soft-tissue treatment objectives.

Evidence from different regions of India further indicates that cephalometric characteristics are not uniform throughout the country. Regional differences in skeletal, dental, and soft-tissue parameters emphasize the limitations of applying generalized normative values to all Indian orthodontic patients. Development and validation of population-specific reference values may therefore improve the accuracy of diagnosis and treatment planning.

Craniofacial morphology is also closely associated with airway dimensions. Skeletal Class II individuals have generally been reported to demonstrate comparatively smaller airway dimensions, whereas

(Fig.4)-Nemostudio softwares showing Traced cephalogram of patient & analysis

METHODOLOGY

Participants satisfying the predetermined eligibility criteria were enrolled in the study. Standardized lateral cephalometric radiographs were obtained with the subjects positioned in the natural head position (NHP). The radiographs were subsequently imported into 2D NemoStudio software for digital tracing and cephalometric assessment.⁵¹ (Fig. 4)

Skeletal Classification

Based on the sagittal skeletal relationship assessed by the ANB angle according to Steiner's analysis, participants were divided into three skeletal groups (Fig. 5):

- **Class I:** ANB angle 0° – 2°
- **Class II:** ANB angle $>2^{\circ}$
- **Class III:** ANB angle $<0^{\circ}$

Each skeletal category was further classified according to the vertical growth pattern using the Frankfort–

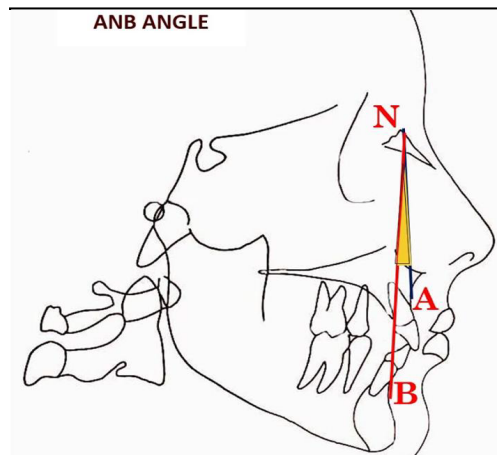
mandibular plane (FH-MP) angle, based on the criteria described by Tweed and Salzmann (Fig. 6):

- **Hypodivergent:** FH-MP angle $<17^{\circ}$
- **Normodivergent:** FH-MP angle 17° – 28°
- **Hyperdivergent:** FH-MP angle $>28^{\circ}$

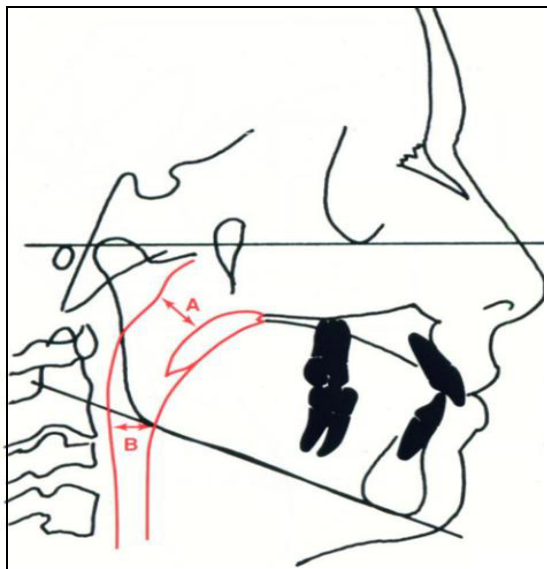
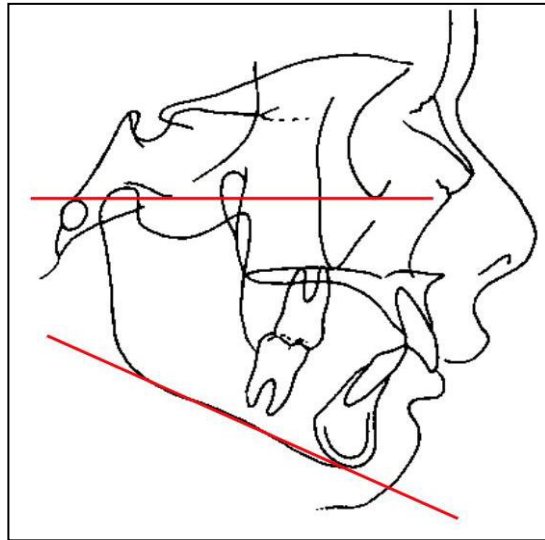
Airway Assessment

Pharyngeal airway dimensions were evaluated using McNamara's cephalometric analysis. The following measurements were recorded (Fig. 7):

- **Upper Airway Width (UAW):** The shortest distance between the posterior surface of the soft palate and the posterior pharyngeal wall (Point A).
- **Lower Airway Width (LAW):** The distance measured from the point where the posterior pharyngeal wall intersects the tongue contour to the inferior border of the mandible (Point B)



(Fig.5)- ANB Angle Measurement



(Fig.7)- A-Upper airway, B-Lower airway

STATISTICAL ANALYSIS

The collected data were statistically evaluated using appropriate analytical methods. Continuous variables were summarized as **mean $\pm$ standard deviation (SD)**. Differences among the study groups were assessed using **one-way analysis of variance (ANOVA)**. When a significant overall difference was observed, **Tukey’s post hoc test** was applied for pairwise comparisons. Statistical significance was established at **$p < 0.05$** .

RESULT

A total of **150 participants** were classified equally into three skeletal groups according to the ANB angle. Each skeletal group was subsequently categorized into hypodivergent, normodivergent, and hyperdivergent growth patterns based on the FH–MP angle. Upper and lower pharyngeal airway dimensions were assessed on standardized lateral cephalograms using NemoStudio software. Descriptive statistics, one-way ANOVA, and Tukey’s post hoc analysis were employed for statistical evaluation.

Airway Characteristics According to Skeletal and Vertical Growth Patterns

Within **Skeletal Class I**, both upper and lower pharyngeal airway measurements differed significantly among the three vertical growth patterns. Airway dimensions followed a progressive reduction from **hypodivergent to normodivergent and hyperdivergent** subjects, with the hypodivergent group demonstrating the greatest airway dimensions (**Tables 1–4; Graphs 1–2**).

Among **Skeletal Class II** subjects, upper airway width demonstrated a significant reduction across the

vertical growth categories, with the highest values recorded in hypodivergent individuals and the lowest in hyperdivergent individuals. For lower airway width, the hypodivergent group exhibited significantly greater measurements, whereas the difference between normodivergent and hyperdivergent groups was not statistically significant. In **Skeletal Class III**, statistically significant differences were observed in both upper and lower airway dimensions across the three vertical growth patterns. The hypodivergent subgroup consistently exhibited the largest airway measurements.

Comparison Among Skeletal Classes

Comparison of the three skeletal groups demonstrated a consistent hierarchy in both upper and lower pharyngeal airway dimensions, with the following trend:

Class III > Class I > Class II.

Tukey’s post hoc analysis demonstrated significantly greater airway dimensions in Class III compared with both Class I and Class II. Conversely, Class II subjects exhibited the narrowest airway measurements among the three skeletal categories.

Overall Findings

Overall, the findings demonstrated that **skeletal Class III subjects had the widest pharyngeal airway dimensions, whereas Class II subjects had the narrowest dimensions**. Irrespective of the sagittal skeletal pattern, the **hypodivergent growth pattern was consistently associated with greater upper and lower airway dimensions**, while hyperdivergent individuals generally demonstrated comparatively reduced airway measurements.

Table 1. Upper pharyngeal width according to skeletal class and growth pattern

Skeletal Class	Growth Pattern	N	Mean (mm)	SD
Class I	Hypodivergent	16	12.563	1.0769
Class I	Normodivergent	16	10.494	0.5335
Class I	Hyperdivergent	18	9.583	0.3869
Class II	Hypodivergent	16	11.762	0.5818

Class II	Normodivergent	16	9.981	0.6695
Class II	Hyperdivergent	18	8.344	0.4488
Class III	Hypodivergent	16	15.737	0.7022
Class III	Normodivergent	16	14.962	0.5162
Class III	Hyperdivergent	18	14.366	0.5881

Table 2. Lower pharyngeal width according to skeletal class and growth pattern

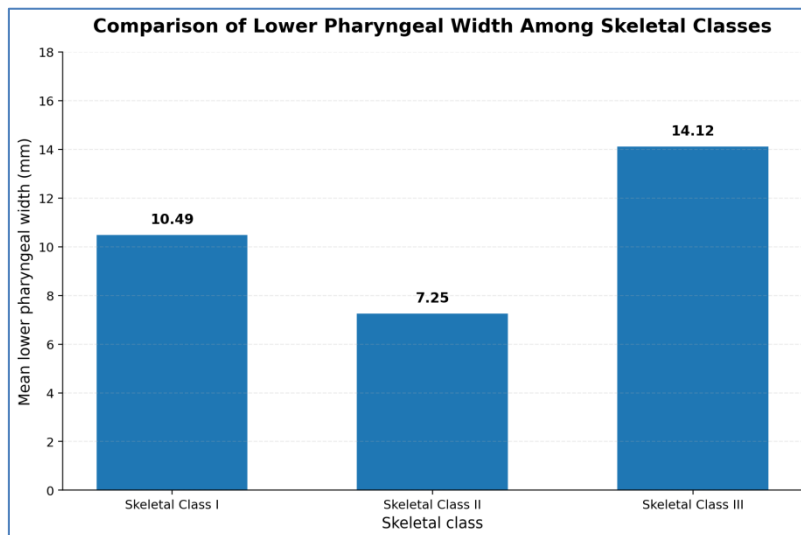
Skeletal Class	Growth Pattern	N	Mean (mm)	SD
Class I	Hypodivergent	16	11.806	0.9132
Class I	Normodivergent	16	10.618	1.0322
Class I	Hyperdivergent	18	9.227	0.4184
Class II	Hypodivergent	16	8.300	0.5633
Class II	Normodivergent	16	6.981	0.4593
Class II	Hyperdivergent	18	6.555	0.6156
Class III	Hypodivergent	16	15.093	0.6668
Class III	Normodivergent	16	14.225	0.4669
Class III	Hyperdivergent	18	13.183	0.3208

Table 3. Pairwise comparison of upper pharyngeal width among skeletal classes

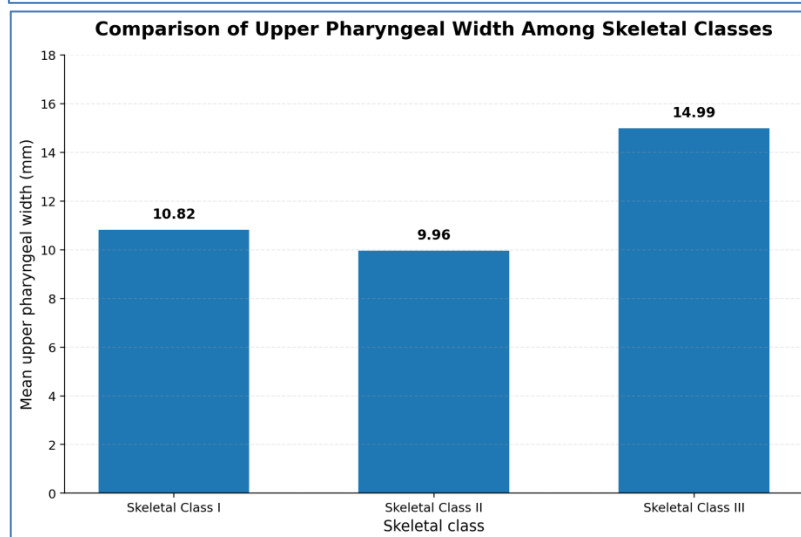
Comparison	Mean Difference (mm)	SE	p-value
Class I vs. Class II	+0.8660	0.2605	0.003
Class III vs. Class I	+4.1680	0.2605	<0.001
Class III vs. Class II	+5.0340	0.2605	<0.001

Table 4. Pairwise comparison of lower pharyngeal width among skeletal classes

Comparison	Mean Difference (mm)	SE	p-value
Class I vs. Class II	+3.2480	0.2160	<0.001
Class III vs. Class I	+3.3700	0.3130	<0.001
Class III vs. Class II	+6.6180	0.3130	<0.001



Graph 2. Mean lower pharyngeal width across skeletal classes



Graph 1. Mean upper pharyngeal width across skeletal classes

DISCUSSION

The present study evaluated the relationship between sagittal skeletal pattern, vertical growth pattern, and pharyngeal airway dimensions using lateral cephalometric analysis. The findings demonstrated that vertical growth pattern had a significant influence on airway dimensions. **Hypodivergent subjects consistently showed wider upper and lower airway spaces, whereas hyperdivergent individuals exhibited reduced dimensions.** This may be attributed to differences in mandibular rotation and the associated positioning of the tongue and hyoid complex. These findings are consistent with the observations of Björk and Skieller⁵⁸, Solow and Tallgren⁵⁹, Joseph et al.⁶⁰, Kim et al.⁶¹, and El and Palomo.⁶²

In **Skeletal Class I**, airway dimensions varied significantly according to vertical growth pattern, with the greatest values observed in hypodivergent and the lowest in hyperdivergent subjects.^{63,64} **Class II** demonstrated the most restricted airway dimensions, particularly among hyperdivergent individuals. Mandibular retrusion and posterior displacement of the tongue may contribute to this reduction, as reported by McNamara⁵⁴ and Battagel et al.⁶⁵. Similar findings have been reported by Haskell et al.⁶⁶ and El and Palomo.⁶²

In **Skeletal Class III**, airway dimensions were comparatively larger, particularly in hypodivergent subjects. The anterior mandibular position may provide increased pharyngeal space, supporting findings reported by Deguchi et al.⁶⁷ and Hong et al.⁶⁸. Overall, airway measurements followed the pattern **Class III > Class I > Class II**, indicating an important

contribution of sagittal skeletal position to airway morphology.

The findings emphasize that both sagittal skeletal relationship and vertical facial pattern should be considered during orthodontic airway assessment. **Hyperdivergent Class II individuals**, in particular, may present with comparatively reduced airway dimensions and therefore warrant careful evaluation during diagnosis and treatment planning.

CONCLUSION

Vertical growth pattern significantly influenced pharyngeal airway dimensions. **Hypodivergent subjects demonstrated the greatest airway dimensions, whereas hyperdivergent individuals showed reduced airway spaces.** Across skeletal groups, airway dimensions followed **Class III > Class I > Class II**, with Class II exhibiting the narrowest dimensions. These findings highlight the importance of incorporating **skeletal pattern and vertical growth assessment** into orthodontic diagnosis and treatment planning.

LIMITATION

The study has certain limitations. **Lateral cephalometry provides only a two-dimensional assessment**, restricting evaluation of the complete three-dimensional airway. The relatively **limited age range and sample characteristics** may also affect the generalizability of the findings. Furthermore, **functional airway parameters during respiration or sleep were not assessed.** Future studies with **larger and diverse populations, longitudinal designs, and three-dimensional imaging such as CBCT** are recommended for more comprehensive evaluation.

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