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Three dimensional analysis of Upper Airway and its correlation with different Growth Patterns of Skeletal Class II: A CBCT Study

Dr. Yusuf A.R.[1], Dr. Priya Roy[2], Dr. Ganger C.R.[3], Dr. Rushikesh S. Kadam[4], Dr. Sharrianne Fernandes[5], Dr. Madhura Mahajan[6]

[1]Associate Professor (Ph.D Scholer) Department Of Orthodontics And Dentofacial Orthopaedics, KVV, Karad

[2]Phd Guide, Professor, Department Of Anatomy, Krishna Institute Of Medical Sciences, KVV, Karad

[3]Phd Co-Guide, Professor And Head, Department Of Orthodontics And Dentofacial Orthopaedics, KVV, Karad

[4] Postgraduate Student, Department Of Orthodontics And Dentofacial Orthopaedics, KVV, Karad

[5]Postgraduate Student, Department Of Orthodontics And Dentofacial Orthopaedics, KVV, Karad

[6]Assistant Professor, Department Of Oral Medicine And Radiology, KVV, Karad

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1. INTRODUCTION

Successful treatment of craniofacial anomalies and dental malocclusions is inherently dependent on an understanding and proper use of the soft tissue and muscle matrix which surrounds the craniofacial skeleton and dento-alveolar process. Stable treatment results depend upon establishing a balanced neuromuscular function of the craniofacial muscles which support the structures in their position. The different size of the pharynx affects the airway volume, facial growth pattern. Anatomical abnormalities of the soft tissue and craniofacial skeleton can change the airway volume. The pathological, physiological and morphological obstructive processes such as hypertrophy of the adenoids and tonsils, allergic and chronic rhinitis, stimulatory environmental factors, congenital nasal deformities, trauma to the nose, polyps and tumors are among the predisposing factors for the superior airway obstruction. The different size of the pharynx affects the airway volume, facial growth pattern. Anatomical abnormalities of the soft tissue and craniofacial skeleton can change the airway volume. The pathological, physiological and morphological obstructive processes such as hypertrophy of the adenoids and tonsils, allergic and chronic rhinitis, stimulatory environmental factors, congenital nasal deformities, trauma to the nose, polyps and tumors are among the predisposing factors for the superior airway obstruction. Most previous studies in this respect had limitations since they evaluated the lateral cephalograms of patients. Lateral cephalometry provides a two-dimensional view of a three-dimensional (3D) structure and it will not asses the volume of structures. Moreover, lateral cephalograms have other shortcomings such as distortion, low reproducibility due to problems in landmark identification, difference in magnification and superimposition of bilateral craniofacial structures. Anatomical boundaries and space of the upper airway as the two main factors playing a role in normal growth and development of the craniofacial complex. Computer Tomography imaging can be utilized to assess the area and dimensions of the airway. Because of high radiation dose and charges , CT SCANS are not used in day today practice . Advance technique such as Cone-beam Computer Tomography (CBCT) is used to detect the abnormalities in airways. Evidence shows that type and severity of malocclusion can affect the size of the pharynx and increase the risk of obstructive respiratory diseases.

Studies suggest that normal respiration affect normal growth and development of facial structures. Deviated respiratory problems is associated with improper airway patency , result in oral breathing. This conversion of mode of respiration lead to oral breathing instead of nasal breathing thus forcing the growing patient mandible autorotate backwards. These abnormal mode of respiration lead to disturbance in craniofacial skeleton. A constricted upper airway region seen commonly in patients Class-ii than in those with Class I malocclusion, because of the variations in the site and the severity of narrowing of the airways, facial dimensions can be different among patients.

Considering the significance of determining the total airway capacity and morphology of the superior airway in different facial patterns and treatment planning, this study was carried out to analyze the pharyngeal airway capacity in different growth patterns. Thus this study is conducted to assess the different skeletal growth patterns affects the airway volume, finding out the co relation between upper airway and its effect on different skeletal pattern in three dimensions of space, in a southwest Maharashtra population using Cone Beam Computer Tomography.

Aim of the Study:

The aim of this study is to assess the co relation between upper airway in skeletal Class-ii and its effect on different skeletal growth pattern in skeletal class II patients using Cone Beam Computer Tomography.

Objectives of the study:

1. Upper airway volume among horizontal growth pattern, average growth pattern and vertical growth pattern.
2. Minimum cross section (MCS) of airway among skeletal class 2 with different growth pattern.
3. Right and left lateral width (Transverse width) of skeletal class 2 in different growth pattern.
4. Co-relation of Total airway volume, upper airway volume and lower airway of skeletal class 2 in different growth pattern with that of SNA ,SNB and ANB angle and Lower Anterior Facial Height (LAFH)
5. Co-relation of minimum cross section(MCS) in skeletal class-ii with that of ANB angle and Lower Anterior Facial Height(LAFH).

2. MATERIAL AND METHODS

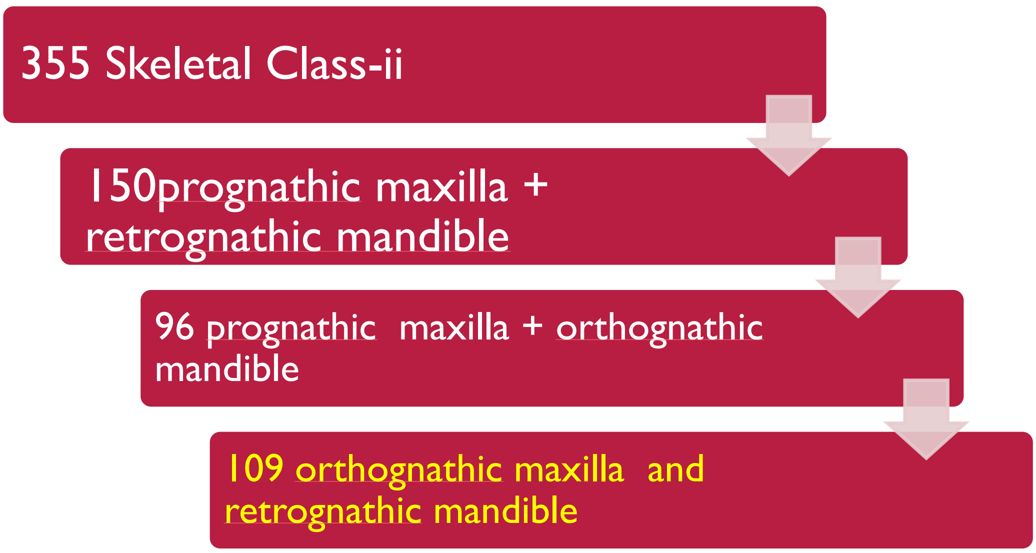
This cross sectional study was conducted in Department of Orthodontics, School of Dental Sciences, Krishna Vishwa Vidyapeeth, Deemed to be University. Karad, Maharashtra. 109 patients selected from Department of orthodontic. The lateral Cepahlogram and CBCT scans of subjects in the study material were selected from the patients visiting the orthodontic department for treatment. The study was approved by the Ethical committee , KVV, KARAD.

- Inclusion criteria –
    1. Skeletal Class-2,
    2. ANB > 4 degrees (orthognathic maxilla and retrognathic mandible)
    3. Age > 13 years and < 18 years.
- The exclusion criteria –
    1. Those with edentulous areas
    2. Severe skeletal asymmetry
    3. Visible jaw fracture on CBCT scans
    4. History of Adenoidectomy
    5. Cleft lip and palate patients
    6. Syndromic patients

Selection process:

355 patients were Screened , visiting the Dental collage for orthodontic treatment (department) in age group between 13 to 18 years .

Lateral cephalograms were traced to find out the SNA ,SNB and ANB angle .



If the values showing SNA 82+2 degrees should be considered in the study.SNB should be less than 80 degrees.

Determination sample size:

$$n = 2\frac{S^2(Z1 + Z2)^2}{(M1 - M2)^2}$$

The Lateral cephalogram are taken with the patient standing in Natural Head position (NHP). Subject's head was secured in cephalostat (CARESTREAM CS 8100SC) Frankfort horizontal plane parallel to floor.

Cephalometric parameters:

Skeletal parameters - SNA, SNB, ANB angle, GO-GN To SN, Y-axis, Lower Anterior Facial Height (LAFH),

Dental parameters - upper incisor NA linear and angular measurement, lower incisor to NB Linear And Angular Measurement.

Skeletal class-ii patients were divided into three groups based on (Go-Gn to Sn), SN plane to GO-GN mandibular Plane angle, thus sample divided into three categories Hypodivergent (less than 25 degree) , Normo divergent (between 25to 30 degree) and Hyperdivergent (angle should be more than 30 degree).

- Number patients per group ;

1. Hypodivergent growth pattern(Horizontal growth pattern) – 35
2. Averagre growth pattern - 36
3. Hyperdivergent growth pattern (Vertical growth pattern) - 38

CBCT scans were taken using CBCT CARESTREAM U.S . CS 9600 , TUBE VOLATGE 60-90 Kv, tube current 2-15 mA, frequency -140 kHz, tubal focal spot – 0.3 or 0.7 mm. Carestream software first standardized and calibrated the 3D head position in the axial, saggittal and frontal planes. In the frontal view, the mid-saggittal plane matched the skeletal midline and the coronal plane matched the line passing from the right and left inferior orbital rims.

On the lateral view, the Frankfurt plane was parallelized and matched the axial plane. Also, the coronal plane matched the line passing along the pterygomaxillary groove in the pterygopalatine fossa. Next, measurements and calculations of the upper and lower naso-pharynx and oro-pharynx volume were made using the sinus/airway feature of the carestream software.

Hormion: The point of union of the sphenoid bone with the posterior border of the vomer (the most superior border of the pharyngeal airway)
Analysis of the airway volume: Software automatically analyses the airway after selecting the land marks right from superior limit of pharynx to (upper airway) to inferior limit (lower airway).Initially , determine the overall volume of upper and lower airway from antero- superior limit of the vertical line (Hormion point) to lower limit of inferior airway , that is limited by a horizontal line tangent to tip of epiglottis which gives the total airway volume of patient, measured in cm3 (cubic centimeter).

After ensuring that the airway was correctly and completely outlined in all three planes, in minimum acceptable sensitivity, the airway volume was calculated using the software. Whenever total volume of airway measured for the patient, the software also measures minimum cross section (MCS) of airway which is in (mm2) square millimeter. Along with minimum cross section this airway software also determines antero-posterior length of airway (Depth) and right –left width of airway (transverse) , both these airway measurements are in millimeter (MM).

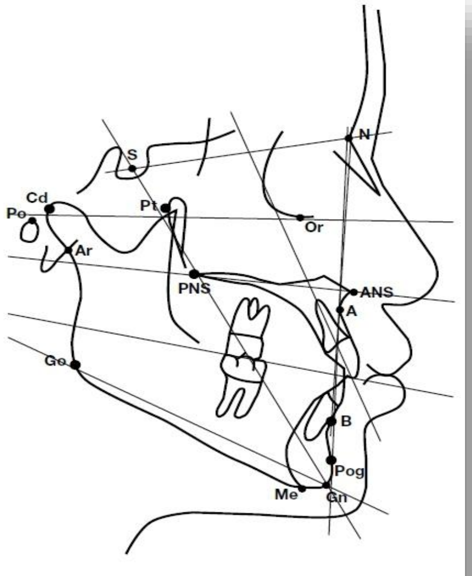


Figure 3. Cephalometric tracing: lines are constructed to join the landmarks for analysis of angular relationships.

CBCT READINGS:

- Upper airway volume
- Minimum cross section (MCS)
- Antero-posterior (depth) of airway (Sagittal dimension)
- Right – left lateral width (Transverse dimension)

All patients lateral cephalograms were traced by single operator and CBCT analysis carried out by single operator. The above all results are tabulated and subjected to statistical analysis. Also correlation drawn between CBCT and Cephalometric skeletal and dental parameters.

<u>Method of data analysis:</u>

Statistical Product and Service Solution (SPSS) version 21 for Windows (Armonk,NY:IBM corp) software was used to analyse the data. Statistical analysis was done by using tools of descriptive statistics such as Mean, and SD for representing quantitative data.

Qualitative data were expressed in percentage. Probability $p<0.05$, considered as significant as alpha error set at 5% with confidence interval of 95% set in the study. Power of the study was set at 80% with beta error set at 20%.

Normality of data was checked using Shapiro Wilk test.

One-way ANOVA test was applied to compare measurements between three groups. Post hoc data analysis which follows One way ANOVA was done by using Tukey's multiple comparison test. Post hoc test analyses multiple pair –wise individual group comparisons.

figure 1 . transeverse dimension of upper airway

figure 2 ; upper airway boundaries and dimension of upper airway in vertical and saggital direction

figure 3; minimum cross section and maximum constriction of airwa

3. OBSERVATION AND RESULTS

Table 1: Comparison of CBCT measurements between three study groups respectively

p>0.05 – not significant *p<0.05 – significant **p<0.001 – highly significant

^p value (pairwise) calculated using Tukey's post hoc test.

	Upper airway Mean (SD)
Group A (Average)	3.87 (1.49)
Group B (Horizontal)	5.72 (1.97)
Group C (Vertical)	4.88 (1.74)
One way Anova F test value	F = 9.838
P value, Significance	p<0.001**
Group A Vs Group B^	P<0.001**
Group A Vs Group C^	p=0.039*
Group B vs Group C^	**P=0.108(NS)**

Table 1; Comparison between Total volume , Upper airway volume and Lower airway volume.

	Upper Airway
Group A (Average)	3.87
Group B (Horizontal)	5.72
Group C (Vertical)	**4.88**

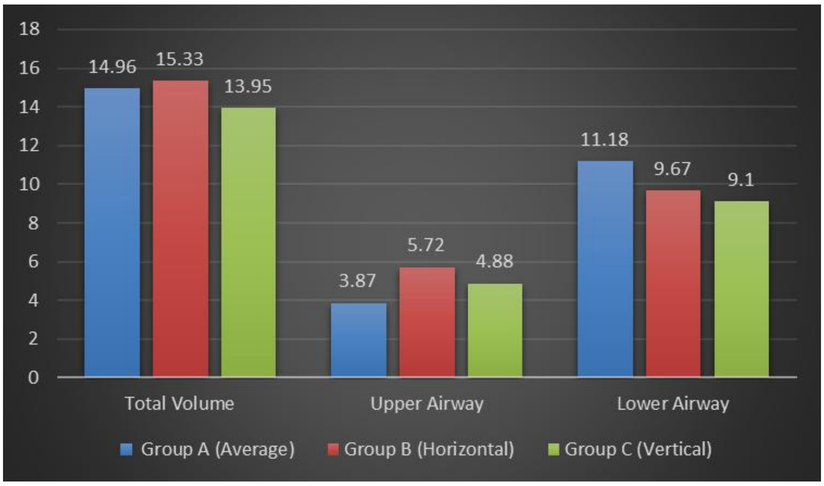


Figure 1; comparison between Total volume, upper airway volume and lower airway volume.

Analysis of CBCT Result;

The study presents a comparative analysis of CBCT (Cone Beam Computed Tomography) measurements across three study groups:

Group A (Average), Group B (Horizontal), and Group C (Vertical). The findings are summarized in two tables, with statistical analyses conducted using 'One-Way ANOVA and Tukey's post hoc test'.

1. Upper Airway Measurements (Table 1).

Upper Airway:

Group B has the highest upper airway volume (5.72 ± 1.97), followed by Group C (4.88 ± 1.74) and Group A (3.87 ± 1.49).

ANOVA test ($p < 0.001$) confirms a highly significant difference, suggesting that upper airway dimensions vary meaningfully between groups.

Pairwise comparisons:

Group A vs Group B: $p < 0.001$ (highly significant difference)

Group A vs Group C; $p = 0.039$ (significant difference)

Group B vs Group C: $p = 0.108$ (NS, not significant)

Implication: Group B exhibits a significantly larger upper airway, potentially due to anatomical differences in horizontal growth patterns**.**

Pairwise comparisons:

Group A vs Group C: $p = 0.029$ (significant)

Group A vs Group B:$p = 0.163$ (NS, not significant)

Group B vs Group C; $p = 0.768$ (NS, not significant)

Table 2: Comparison of CBCT measurements between three study groups respectively

p>0.05 – not significant *p<0.05 – significant **p<0.001 – highly significant

^p value (pairwise) calculated using Tukey's post hoc test

	Minimum cross section Mean (SD) MM2	**Transverse view Mean (SD) MM**	**AP view Mean (SD) MM**
Group A (Average)	170.07 (76.09)	18.62 (6.04)	9.27 (3.14)
Group B (Horizontal)	158.64 (78.5)	19.75 (5.46)	9.81 (3.09)

Group C (Vertical)	139.7 (89.41)	16.32 (5.24)	10.73 (2.8)
One way Anova F test value	F = 1.306	F = 3.557	F = 2.242
P value, Significance	P=0.275(NS)	P=0.032*	P=0.111(NS)
Group A Vs Group B^	P=0.829(NS)	P=0.677(NS)	P=0.732(NS)
Group A Vs Group C^	P=0.251(NS)	P=0.185(NS)	P=0.097(NS)
Group B vs Group C^	P=0.590(NS)	P=0.029*	P=0.400(NS)

comparison between total minimum cross section , transverse view and antero posterior view.

	Minimum cross section	**Transverse view**	**AP view**
Group A (Average)	170.07	18.62	**9.27**
Group B (Horizontal)	158.64	19.75	**9.81**
Group C (Vertical)	**139.7**	**16.32**	**10.73**

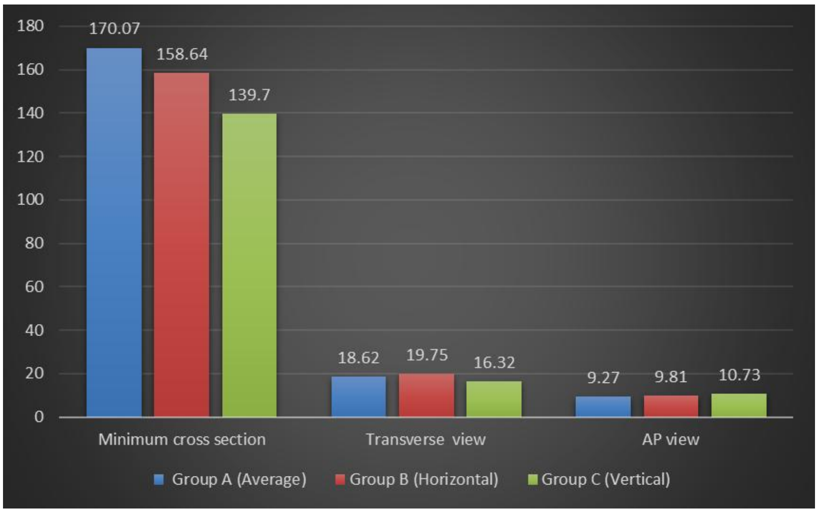


Figure 2; comparison between total minimum cross section, transverse view and antero posterior view .

2. Minimum Cross Section, Transverse, and AP Views (Table 2)

Minimum Cross Section: (MCS)

Group A has the highest minimum cross-sectional area (170.07 ± 76.09), followed by Group B (158.64 ± 78.5) and Group C (139.7 ± 89.41).

However, ANOVA test (p = 0.275) shows no statistically significant difference.

<u>Transverse View;</u>

Group B has the highest transverse view measurement (19.75 ± 5.46), while Group C has the lowest (16.32 ± 5.24).

ANOVA test (p = 0.032) suggests a significant difference.

Pairwise comparisons:

Group B vs Group C: p = 0.029 (significant)

Other comparisons are not significant.

Implication: The horizontal growth pattern (Group B) is associated with a significantly wider transverse airway, supporting the notion that facial growth direction influences airway width.

AP View (Anterior-Posterior):

Group C shows the highest AP measurement (10.73 ± 2.8), compared to Group B (9.81 ± 3.09) and Group A (9.27 ± 3.14).

p = 0. ANOVA test (111) is not significant, meaning AP differences are not statistically relevant.

Overall Interpretation

1. Airway volume varies across different facial growth patterns but is most significantly different in the upper airway (p < 0.001).

2. Horizontal growers (Group B) tend to have a wider airway, particularly in the upper airway and transverse dimensions.

3. Vertical growers (Group C) exhibit a narrower airway, with lower airway volume being significantly smaller compared to the average growth group.

4. Total volume and minimum cross-sectional area do not show significant differences, suggesting that overall airway capacity remains relatively stable across groups despite shape differences.

Table 3 : Correlation of lower facial height parameter (cephalometric) with upper airway (CBCT) in different growth patterns respectively

p>0.05 – no significant difference

Average growth	**Pearson ‘r’ correlation test**	**P value, Significance**
Lower facial height **X** **Upper airway**	r = - 0.173	p=0.305 (NS)
Horizontal growth pattern	Pearson ‘r’ correlation test	P value, Significance
Lower facial height **X** **Upper airway**	r = - 0.057	P=0.742 (NS)
Vertical growth pattern	Pearson ‘r’ correlation test	P value, Significance
Lower facial height **X** **Upper airway**	R =0.032	P=0.812 (NS)

Table 4: Comparison of lateral cephalometric between three study groups respectively

*p>0.05 – not significant *p<0.05 – significant **p<0.001 – highly significant*

^p value (pairwise) calculated using Tukey's post hoc test

	SNA Mean (SD)	SNB Mean (SD)	ANB Mean (SD)
Group A (Average)	79.45 (1.81)	74.89 (0.96)	**5.04 (0.74)**
Group B (Horizontal)	80.5 (4.79)	76.58 (2.94)	**4.36 (4.98)**
Group C (Vertical)	79.23 (4.42)	73.83 (4.01)	**6.35 (5.5)**
One way Anova F test value	F =1.170	F =8.494	**F = 2.340**
P value, Significance	p= 0.314	p<0.001**	**p=0.101**
Group A Vs Group B^	p=0.506	p=0.057	**p=0.796**
Group A Vs Group C^	p=0.961	p=0.252	**p=0.354**
Group B vs Group C^	**p=0.299**	**p<0.001****	**p=0.09**

Table 5; Comparison of SNA, SNB ,ANB between average ,horizontal and vertical grower .

	SNA	SNB	ANB
Group A (Average)	79.45	74.89	**5.04**
Group B (Horizontal)	80.5	76.58	**4.36**
Group C (Vertical)	**79.23**	**73.83**	**6.35**

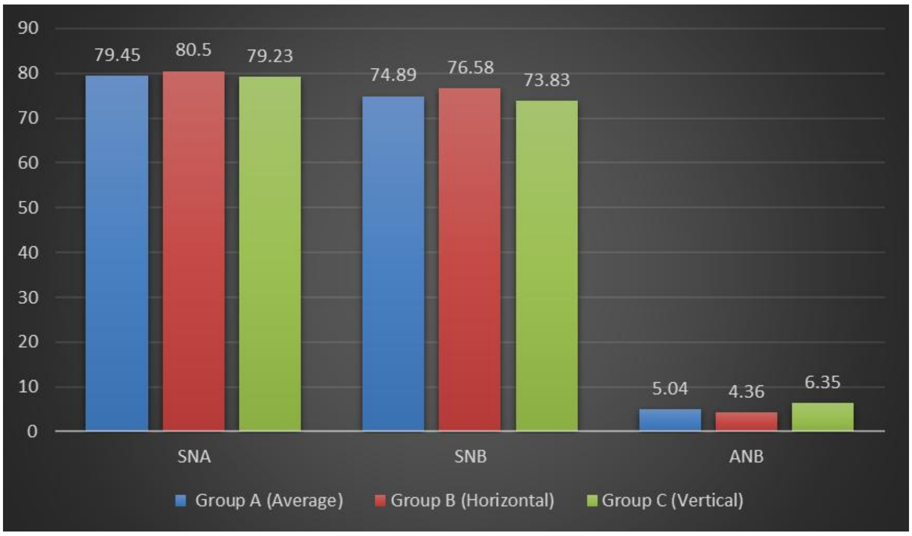


Figure 5; comparison of SNA, SNB ,ANB between average ,horizontal and vertical grower .

Table 6: Comparison of lateral cephalometric between three study groups respectively

*p>0.05 – not significant *p<0.05 – significant **p<0.001 – highly significant*

^p value (pairwise) calculated using Tukey's post hoc test

	SN-GO-GN Mean (SD)	**Facial Axis Angle Mean (SD)**	**Lower Facial Height Mean (SD)**
Group A (Average)	30.97 (1.72)	-3.4 (3.26)	**40.45 (3.34)**
Group B (Horizontal)	26.19 (4.3)	-2.52 (2.78)	**37.13 (2.0)**
Group C (Vertical)	36.89 (3.85)	-5.19 (5.75)	**57.78 (4.3)**
One way Anova F test value	F = 103.43	F = 4.347	**F = 4 67.64**
P value, Significance	P<0.001**	P=0.015*	**P<0.001****
Group A Vs Group B^	P<0.001**	P=0.675	**P<0.001****
Group A Vs Group C^	P<0.001**	P=0.141	**P<0.001****
Group B vs Group C^	**P<0.001****	**P=0.015***	**P<0.001****

Table 7; Comparison between SN-GO-GN , Facial axis angle and lower anterior facial height in Average grower , Horizontal grower and Vertical grower .

	SN-GO-GN	Facial axis angle	Lower Anterior Facial Height
Group A (Average)	30.97	-3.4	**40.45**
Group B (Horizontal)	26.19	-2.52	**37.13**
Group C (Vertical)	**36.89**	**-5.19**	**57.78**

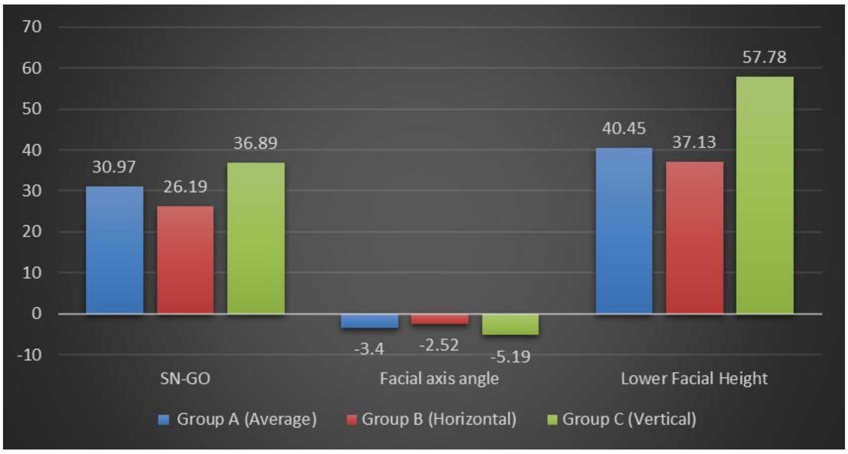


Figure 6; Comparison between SN-GO-GN , Facial axis angle and lower anterior facial height in Average grower , Horizontal grower and Vertical grower

Table 8: Comparison of lateral cephalometric between three study groups respectively

*p>0.05 – not significant *p<0.05 – significant **p<0.001 – highly significant*

^p value (pairwise) calculated using Tukey's post hoc test

	UI to NA Angle Mean (SD)	UI to NA Linear	LI to NB Angle	LI to NB Linear
Group A (Average)	31.48 (9.92)	8.54 (3.66)	25.78 (4.45)	**5.594 (1.67)**
Group B (Horizontal)	35.27 (6.27)	8.13 (2.69)	24.33 (8.13)	**4.91 (2.66)**
Group C (Vertical)	30.91 (7.33)	8.07 (2.57)	28.46 (8.48)	**6.82 (2.79)**
One way Anova F test value	F = 3.612	F =0.301	F = 3.640	**F =6.934**
P value, Significance	P=0.03*	P=0.741	P=0.029*	**P=0.001***

Group A Vs Group B^	P=0.105	P=0.831	P=0.684	**P=0.476**
Group A Vs Group C^	P=0.937	P=0.735	P=0.210	**P=0.055**
Group B vs Group C^	**P=0.029***	**P=0.994**	**p=0.028***	**P=0.001***

Table 9; Comparison between upper incisor to NA(angle and linear) and lower incisor to NB (angle and linear) in Average grower , Horizontal grower and Vertical grower .

	UI to NA Angle	**UI to NA Linear**	**LI to NB Angle**	**LI to NB Linear**
Group A (Average)	31.48	8.54	25.78	**5.594**
Group B (Horizontal)	35.27	8.13	24.33	**4.91**
Group C (Vertical)	**30.97**	**8.07**	**28.46**	**6.82**

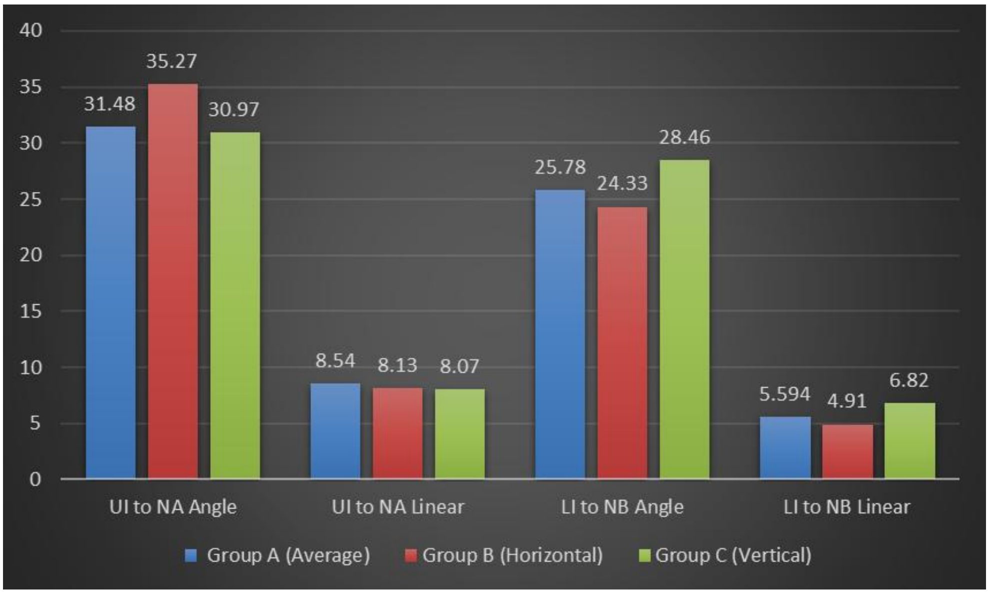


Figure 7; Comparison between upper incisor to NA(angle and linear) and lower incisor to NB (angle and linear) in Average grower , Horizontal grower and Vertical grower

2. Analysis of Lateral Cephalometric Measurements Between Study Groups;

The study presents a comparative analysis of lateral cephalometric measurements across three study groups:

Group A (Average Growth Pattern)

Group B (Horizontal Growth Pattern)

Group C (Vertical Growth Pattern)

Statistical comparisons were conducted using One-Way ANOVA and Tukey's post hoc test to determine significant differences between groups.

1. Angular and Linear Cephalometric Parameters (Table 2 & Table 3).

SNB shows a highly significant difference ($p < 0.001$), indicating mandibular positioning variations between growth patterns. Group B (Horizontal) has a more anteriorly positioned mandible, while Group C (Vertical) has a more retruded mandible.

ANB values are higher in Group C, which may indicate greater skeletal Class II tendency in vertical growers, but it does not reach statistical significance ($p = 0.101$).

2. Skeletal and Facial Growth Angles ;

| Parameter | Group A (Avg) | Group B (Horiz.) | Group C (Vert.) | ANOVA F-Value | P-Value | Interpretation |

SN-GoGn (30.97 ± 1.72) (26.19 ± 4.3) (36.89 ± 3.85) (**103.43) p < 0.001.

Highly significant difference in mandibular plane angle.

Facial Axis Angle (-3.4 ± 3.26) (-2.52 ± 2.78) (-5.19 ± 5.75) (4.347) p = 0.015**

Significant difference .

Lower Facial Height (mm) (40.45 ± 3.34) (37.13 ± 2.0) (57.78 ± 4.3) (467.64) p < 0.001

Highly significant difference .

SN-GoGn (Mandibular Plane Angle) shows highly significant differences ($p < 0.001$).

Group B (Horizontal) has the lowest angle (16.19°), **indicating a flatter mandibular plane**.

Group C (Vertical) has the highest angle (36.89°), reflecting a steep mandibular plane commonly seen in vertical growers.

Lower Facial Height is significantly greater in Group C (Vertical) , suggesting that dolicofacial growers have increased lower facial proportions compared to horizontal and average growth patterns.

Facial Axis Angle is significantly different ($p = 0.015$) but not as strongly as the other parameters.

3. Dental Measurements (UI-NA, LI-NB)

Upper and lower incisor inclinations (UI-NA, LI-NB Angles) differ significantly between groups.

UI-NA is significantly higher in Group B (35.27°), indicating greater proclination of upper incisors in horizontal growers.

LI-NB is significantly higher in Group C (28.46°), meaning lower incisors are more proclined in vertical growers.

LI-NB Linear measurement (lower incisor protrusion) is highly significant ($p = 0.001$), suggesting that lower incisor positioning varies greatly between growth patterns, with vertical growers having more protruded lower incisors.

4. OVERALL IMPRESSION

Understanding these cephalometric differences is crucial for orthodontic diagnosis and treatment planning.

Vertical growers may require bite control strategies, while horizontal growers may need expansion treatments.

This study confirms significant cephalometric differences between horizontal, vertical, and average growth patterns in terms of skeletal, facial, and dental parameters. Mandibular positioning, lower facial height, and incisor inclinations are key differentiating factors. These findings are essential for orthodontic diagnosis and personalized treatment planning.

5. DISCUSSION

The adenoid is a mass of lymphatic tissue located in the posterior region of the nasal airway. Narrowing of the posterior airway, caused by genetic factors or frequent adenoid infections and inflammation, has been linked to changes in craniofacial development. This can lead to the "Adenoid face" appearance, characterized by a narrow upper jaw, a posterior crossbite, a longer face, and a receded lower jaw. Research shows that adenoid should regress by 12 yrs of the age in male but it is even less in female patient (Scammon’s growth curve theory). The nasopharyngeal airway is mainly influenced by the adenoids, which follow a growth pattern described by Scammon et al. These adenoids grow rapidly from infancy, peak before adolescence, and then gradually shrink to their adult size. Subtelny and Baker concluded that the adenoid growth peak typically occurs between 9 and 12 years of age. In our study, children aged above 13 years were selected. Total volume of the airway in vertical growth pattern is less than horizontal and average growth pattern because of downward and backward rotation of mandible which decreases the total airway space and volume.

The study by Aphale et al. found that individuals with a vertical growth pattern had notably narrower upper airway dimensions compared to those with horizontal or average growth patterns. Additionally, individuals with hyperdivergent growth patterns had significantly smaller upper and lower pharyngeal airways than those with normodivergent or hypodivergent growth patterns. The sagittal relationship affects upper airway dimensions, with individuals having a skeletal Class II normo divergent growth pattern showing significantly narrower upper airway dimensions compared to those with a skeletal Class I normodivergent growth Pattern. In our study we found similar results . Additionally, individuals with a skeletal Class II hyperdivergent growth pattern have significantly smaller lower airway dimensions compared to those with a skeletal Class I hyperdivergent growth pattern Ackerman and Klapper and Linder-Aronson and Backstrom showed similar results.

The study by Marcos Roberto de Freitas et al. found that the upper pharyngeal width in individuals with Class II malocclusions and vertical growth patterns was significantly narrower compared to those with normal growth patterns. Additionally, individuals with Class II malocclusions and vertical growth patterns had significantly narrower upper pharyngeal airways than those with Class II malocclusions and normal growth patterns. In addition to the findings of Yoon-Ji Kim et al, studies have supported the association between airway volume and skeletal relationships, particularly in retrognathic patients. Yoon-ji kim et al suggested that retrognathic patients also exhibited a reduction in airway volume, especially in the regions extending from the anterior nasal cavity to the epiglottis. In our study we found similar results as there is close association between total airway volume and skeletal relationship, vertical growth pattern shows significant reduction upper and lower volume.

Kochhar et al, in their study, compared the means and standard deviations of various cephalometric, cross-sectional, and volumetric variables. The mean total airway volume in patients with a retrognathic mandible was significantly smaller compared to that of patients with a normal mandible. These findings are similar to our study , that retrognathic mandible has lower volumetric values.

Ji-suk Hong et al. found that the cross-sectional areas of the lower part of the pharyngeal airway and the volume of the upper part of the pharyngeal airway were lesser in patients with skeletal Class II malocclusion. Additionally, the volume of the upper part of the pharyngeal airway showed negative correlations with the ANB angle and positive correlations with various measurements such as SNB, FMA.

Their study concluded that the increased volume of the upper pharyngeal airway in Class II patients with horizontal growth pattern , was significantly associated with measurements indicating a more anterior position of the mandible. Upper airway volume among average growth pattern, horizontal growth pattern, and vertical growth pattern. Implication: Group B exhibits a significantly larger upper airway, potentially due to anatomical differences in horizontal growth patterns.

In contrary to this, vertical growth pattern in skeletal class 2 has narrower upper airway pattern, the presence of adenoid even in small amount will obstruct normal breathing posing the growing child to breath through mouth. In contrast to this horizontal growers the presence of adenoid will be compensated transversely and antero-posteriorly thus nasal breathing will be less compromised.

In our study, we found that the highest upper airway volume was observed in patients with a horizontal growth pattern. This increase in upper airway volume can be attributed to a compensatory mechanism, where the upper airway width expands as a response to the skeletal changes associated with horizontal growth. Ji-Suk Honget et al, studies shows similar results. Also, patients with a narrow upper airway show compensatory increased airway width and anterior growth of the jaws during puberty.

Our study results are similar to those of Sunilkumar L. Nagmode et al, study shows that subjects with a vertical pattern of growth also had significantly narrower upper airway dimensions as compared to those with a horizontal and an average pattern of growth . Roberto de Freitas et al. study results showed that the upper pharyngeal width in subjects with Class II malocclusions and vertical growth patterns was significantly narrower compared to those in the normal growth pattern groups. This finding suggests that vertical growth patterns, often associated with skeletal malocclusions like Class II, may contribute to a reduction in the width of the upper pharyngeal airway. The narrower airway in these patients could potentially increase the risk of airway obstruction or related breathing issues. These results emphasize the impact of growth patterns on airway dimensions and highlight the need for careful evaluation of airway space in patients with vertical growth tendencies to guide effective treatment planning.

Ana Paula Flores-Blancas' study found similar results , with subjects exhibiting a brachyfacial pattern presenting larger nasopharyngeal widths compared to those with mesofacial ($p = 0.030$) or dolichofacial ($p = 0.034$) patterns. This suggests that individuals with a brachyfacial pattern, characterized by a shorter, broader facial structure, tend to have a wider nasopharyngeal airway compared to those with more vertical or average facial structures. These findings align with our observations, indicating that facial and skeletal growth patterns play a crucial role in determining airway dimensions.

The wider nasopharyngeal airway in brachyfacial individuals could be a factor in better airflow and fewer respiratory issues compared to those with other facial types. Linder -Aronson studied the relationship of upper and lower parts of the airway, and reported that a small nasopharyngeal airway is accompanied by a larger oro-pharyngeal airway. Rickets and Dunn et al stated that oral breathing is related to a narrow nasopharyngeal airway width because it is easily blocked by adenoid enlargement.

Roberto de Freitas et al. showed that the upper pharyngeal width in subjects with Class II malocclusions and vertical growth patterns was statistically significantly narrower than in the normal growth-pattern groups. These findings are in agreement with the results of our study, we observed that individuals with a vertical growth pattern exhibited narrower upper and lower airways. The presence of adenoid tissue in these patients contributes to the reduction in the upper airway space.

Abbas Shokri et al, The minimum axial area and airway morphology in class III patients were greater than those in class I and II patients. The effect of ANB angle on airway volume was statistically significant and it was shown that one unit increase in the angle decreased the airway volume by 453.509 units. In this study significant correlation exists between the skeletal facial pattern and upper airway dimensions. Total airway volume was significantly correlated with ANB angle ($p<0.05$). These findings are similar to results of our study, there is close association between total airway volume and ANB angle.

Paul, et al , results suggest a strong association between airway dimensions and skeletal pattern, particularly highlighting a reduced airway in Class II patients with a high ANB angle. This reinforces the notion that skeletal discrepancies, particularly in Class II malocclusion, can lead to compromised airway dimensions, which may have implications for breathing and other related health conditions.

Ligia Vieira Claudino et al. showed in their study that the Class II group had a statistically significant different morphology in the velopharynx compared to the Class I and Class III groups. This suggests that Class II malocclusion is associated with unique airway characteristics, particularly in the velopharyngeal region. Additionally, subjects with a brachyfacial pattern presented larger nasopharyngeal widths compared to those with mesofacial or dolichofacial patterns, indicating that facial type plays a significant role in determining airway dimensions.

Minimum Cross Section: The standard deviations of the airway dimensions were significantly large in cross-sectional area and volumetric measurements. This agreed with the findings of Ozbek et al, who analyzed airway dimensions including width, area, and angulation in lateral headfilms of skeletal Class II growing children. The area measurement of the oropharnynx had large standard deviations, whereas the rest of the measurements such as airway width and angulation showed narrow ranges.

In our study minimum cross section (MCS) of airway in horizontal growth pattern is larger than the average growth pattern and vertical growth pattern.

Subjects with brachyfacial pattern presented larger nasopharyngeal widths than subjects with mesofacial ($p=0.030$) or dolichofacial ($p=0.034$) patterns. In Class II subjects, the minimum and mean areas in the lower portion, velopharynx, and oropharynx were smaller compared to the Class III group, with the Class II group showing significantly less uniform velopharyngeal morphology . These findings suggest that Class II malocclusion, particularly with a higher ANB angle, is associated with reduced airway dimensions in specific regions of the pharynx, which may contribute to an increased risk of airway-related issues such as mouth breathing and obstructive sleep apnea.

Zheng Z. H., Yamaguchi T et al , study shows that The nasopharyngeal airway (NA) volume of Class I and Class III subjects was significantly larger than that of Class II subjects ($p < 0.05$). The Min CSA and the length of PA were significantly related to the volume of PA . The site and the size of the Min-CSA varied among the three groups. In this study The volume and the most constricted cross-sectional area of the airway varied with different anteroposterior skeletal patterns. The findings of the study are similar to findings of our study about the minimum cross section of airway.

Right and left lateral width (Transverse width): In horizontal growth pattern (brachyfacial) individual there is larger transverse dimension , because of wider mandible thus increased transverse dimension . If there is Adenoid in upper airway in horizontal growth pattern there is compensatory increase in the transverse width of airway. This is in contrast to vertical growth pattern where in there is decrease in the transverse dimension because of inherent vertical growth pattern . Thus if there is adenoid in upper airway there is problem with breathing pattern.

Antero-posterior (Depth) of airway : In vertical growth pattern, there is downward and backward roation of mandible. because of mouth breathing habit which may lead to decrease in the anteroposrtior dimension. Ana Paula et al, study shows that nasopharyngeal anteroposterior linear depth in skeletal Class II malocclusion in brachyfacial individuals are lesser than in mesofacial and dolichofacial individuals. This suggests that brachyfacial individuals, characterized by a shorter and broader facial structure, tend to have a wider nasopharyngeal airway compared to individuals with other facial patterns. However, no significant differences were noted for oropharyngeal widths, indicating that the variations in airway size are more pronounced in the nasopharyngeal region. Additionally, a positive correlation was found between nasopharyngeal widths and vertical facial pattern, although the Vertical index only explained 25% of the total variability. This suggests that while vertical facial patterns can influence nasopharyngeal width, other factors also contribute to airway dimensions.

SNA, SNB, and ANB Angles

SNB shows a highly significant difference ($p < 0.001$), indicating mandibular positioning variations between growth patterns. Group B (Horizontal) has a more anteriorly positioned mandible, while Group C (Vertical) has a more retruded mandible.

ANB values are higher in Group C, which may indicate greater skeletal Class II tendency in vertical growers, but it does not reach statistical significance (p = 0.101).

Ji-Suk Honget al studies shows similar results; The volume of the upper part of the pharyngeal airway showed negative correlations with the ANB angle and the Wits appraisal, indicating that as the ANB angle increases (suggesting a more pronounced Class II skeletal relationship). On the other hand, a positive correlation with the SNB angle suggests that a more anteriorly positioned mandible (as reflected by a higher SNB angle) is associated with a smaller upper pharyngeal airway volume. These findings highlight the relationship between skeletal alignment, particularly the position of the mandible, and the size of the upper airway, which may have significant implications for both airway health and treatment planning in orthodontics and orthognathic surgery.

Ligia Vieira Claudino, study shows that A negative correlation was observed between the ANB value and airway volume in the lower pharyngeal portion . The ANB angle is a commonly used cephalometric parameter in clinical orthodontics, Ishikawa et al. corroborated that the ANB angle is reliable for determining the antero-posterior relationship of the jaws.

Additionally, these authors demonstrated that both the ANB angle and the angle of convexity in prepubertal assessments have high prediction accuracy for postpubertal jaw relationships. This suggests that these cephalometric measurements can be valuable tools in predicting future skeletal development and guiding treatment planning. In preadolescents, our study found that volumetric measurements of the airway are significantly correlated with anteroposterior and vertical cephalometric variables, particularly anterior facial height and the ANB angle. This highlights the complexity of the relationship between skeletal growth patterns and airway dimensions, as the effect of vertical growth on airway size can vary across different populations and stages of development.

In our study, the vertical growth pattern showed an increased ANB with an increased lower anterior facial height. The findings are consistent with those of Bollhalder, Julia et al. In their study, the group with higher ANB values exhibited a more vertical skeletal pattern. Additionally, the intermaxillary divergence was found to statistically significantly correlate with the SNA, SNB, and SN/Pg angles. This suggests that the relationship between vertical growth patterns and skeletal parameters, such as the ANB angle, is crucial in understanding airway dimensions and craniofacial morphology, and it can help guide treatment strategies in orthodontics and jaw alignment.

Lower anterior Facial Height (LAFH): Lower Facial Height is significantly greater in Group C (Vertical) , confirming that vertical growth patterns have increased lower facial proportions compared to horizontal and average growth patterns. Facial Axis Angle is significantly different (p = 0.015) but not as strongly as the other parameters. In contrast to these findings in horizontal growth pattern even in increased upper airway there is no increase in the lower facial height because of brachyfacial growth pattern ,where ramus compensation is occurred so that there is no increase in the lower anterior facial height .

6. OVERALL INTERPRETATION

<u>Skeletal Differences:</u>

Horizontal growth (Group B) is characterized by a more anteriorly positioned mandible (higher SNB), flatter mandibular plane, and reduced lower facial height.

Vertical growth (Group C) exhibits a steeper mandibular plane, increased lower facial height, and a more retrognathic mandible.

<u>Dental Inclinations:</u>

Upper incisors are more proclined in horizontal growers (Group B).

Lower incisors are more proclined and protruded in vertical growers (Group C).

Understanding these cephalometric differences is crucial for orthodontic diagnosis and treatment planning. Vertical growers may require bite control strategies, while horizontal growers may need expansion treatments.

In our study findings there is close association between vertical growth pattern and lower anterior facial height, because of decreased upper airway space , mandible rotated downwards and backwards resulting in a increased lower anterior facial height. In conrtast to these findings in horizontal growth pattern even in reduced upper airway there is no increase in the lower facial height, Ackmen Et Al Findings Similar Results As Ours.

7. SUMMARY AND CONCLUSION

This study aimed to explore a potential significant relationship between airway size and maxilla-mandibular growth patterns in healthy preadolescent patients:

1. Precise volumetric measurement of the 3D pharyngeal airway in preadolescents is achievable using CBCT scans.

2. No sexual dimorphism was observed in either the 2D lateral cephalometric analysis or the 3D airway measurements of preadolescents.
3. The mean total airway volume, spanning from the nasopharynx to the epiglottis, was significantly smaller in skeletal class 2 children with vertical growth patterns compared to those with horizontal growth patterns and average growth patterns.
4. In preadolescents, volumetric airway measurements showed significant correlations with anteroposterior and vertical cephalometric variables, primarily anterior facial height and the ANB angle.
5. CBCT of upper airway in horizontal growth pattern shows increased values because of inherent growth pattern and compensation in horizontal direction .In contrary to that in vertical growth pattern there is less transverse values if there is reduction of space in upper airway.
6. Skeletal Differences: Horizontal growth (Group B) is characterized by a more anteriorly positioned mandible (lesser SNB), flatter mandibular plane, and reduced lower facial height. Vertical growth (Group C) exhibits a steeper mandibular plane, increased lower facial height, and a more retrognathic mandible.
7. Dental Inclinations: Upper incisors are more proclined in horizontal growers. Vertical growers show more protruded and proclined lower incisors, this proclination of lower incisors is because of natural compensation for skeletal class 2.

The CBCT analysis reveals that upper airway volume and transverse airway dimensions vary significantly between growth patterns, with horizontal growers having the widest airways and vertical growers the narrowest .

These findings may have clinical implications in orthodontics, respiratory health, and maxillofacial development.

Data from this study is utilised further to study patients with Obstructive sleep apnea. Upper airway CBCT data and analysis can be used by ENT SURGEONS for the diagnosis and treatment planning of Adenoidectomy. Long term studies required so that different orthodontic appliances effect on upper and lower airway should be assessed .

8. FUTURE DIRECTION

It is crucial to determine the most appropriate treatment for each patient, ensuring that treatments do not negatively impact airway dimensions in individuals already predisposed to having smaller airways.

Longitudinal studies tracking airway changes in individuals with different skeletal patterns throughout specific periods of craniofacial growth and development are needed to provide a deeper understanding of the relationship between upper airway morphology, function, and cranio-maxillofacial characteristics.

The upper airway and surrounding soft tissues may adapt to a new position resulting in volumetric changes in the airway.

The sagittal depth of bony nasopharynx is relatively independent of other cephalometric measurements of the facial complex .

This suggests that future research efforts should be directed toward determining what are the effects of environmental and physiological factors are on the size of the airway.

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