

Factors Influencing Upper Airway Dimensions in Skeletal Class II Children and Adolescents: A CBCT Study

Byounghwa Kim¹, Jewoo Lee², Jiyoung Ra²

¹*Department of Pediatric Dentistry, College of Dentistry, Wonkwang University*

²*Department of Pediatric Dentistry and Dental Research Institute, College of Dentistry, Wonkwang University*

Abstract

The purpose of this study is to investigate factors influencing the upper airway dimensions in skeletal Class II children and adolescents.

In total, 67 patients were selected. Airway volume and minimal cross-sectional area were three-dimensionally assessed. Craniofacial morphology and skeletal maturity were assessed on generated two-dimensional cephalograms. The measurements were analyzed using Mann-Whitney test, one-way ANOVA, Pearson's correlation, and multiple regression analysis.

Upper airway dimensions were significantly smaller in pre-peak stage group, and positively associated with age. Anterior facial height and age were the most relevant factors for airway volume. Mandibular width and age were the most relevant factors for minimal cross-sectional area.

Upper airway dimensions were significantly associated with age, skeletal maturity and craniofacial morphology in all three planes.

Key words : Upper airway dimensions, Skeletal Class II pattern, Cone-beam computed tomography

I. Introduction

The effects of respiratory function on craniofacial growth have been studied for decades. More recently, the association between upper airway configurations, craniofacial development, and sleep-disordered breathing (SDB) has been studied[1,2]. Studies on the association between upper airway dimensions and craniofacial morphology have shown that skeletal Class III patients have a greater airway volume and

minimal cross-sectional area than skeletal Class I and Class II patients[3-6].

The association between upper airway space and SDB has been confirmed through various studies. Arens *et al.*[7] reported that in patients with SDB, the upper airway has a significantly smaller cross-sectional area and volume than that in healthy patients. Kim *et al.*[8] reported that patients with severe SDB had a smaller upper airway width.

As maxillofacial growth can be influenced by airway dimen-

Corresponding author : Jiyoung Ra

Department of Pediatric Dentistry, College of Dentistry, Wonkwang University, 895 Muwang-ro, Iksan, Jeollabuk-do, 54538, Republic of Korea

Tel: +82-63-850-6633 / Fax: +82-63-858-2957 / E-mail: pedojoy@wku.ac.kr

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sions, airway assessment is important in growing patients. There are 2 methods of airway assessment: using lateral cephalograms and cone-beam computed tomography (CBCT) images. A two-dimensional (2D) assessment using skeletal and soft tissue landmarks on a lateral cephalogram lacks accuracy with respect to the actual airway size or structure. Three-dimensionally (3D) reconstructed images from CBCT provide stereoscopic images of the airway and enable measurement of the cross-sectional area and volume of the airway space.

Few studies conducted in Korea have used CBCT to analyze the upper airway space in pediatric patients with skeletal Class II malocclusion. In addition, research on associations between the vertical and transverse craniofacial morphology and the upper airway dimension is limited.

This study aimed to investigate factors influencing the upper airway dimensions in pediatric skeletal Class II patients by assessing the correlations with gender, age, skeletal maturity, and craniofacial dimensions.

II. Materials and Methods

This retrospective study was approved by the institutional review board (IRB) of the Wonkwang University (WK-IRB202003-02).

1. Subjects

This study retrospectively analyzed 232 patients who had undergone CBCT due to supernumerary teeth, impacted

teeth, cystic lesion and orthodontic/surgical reasons at the Wonkwang University Dental Hospital from 2014 to 2019. The inclusion criteria were (1) patients between 8 and 15 years of age, (2) A point-nasion-B point (ANB) angle $\geq 4^\circ$, (3) biting in centric occlusion, and (4) CBCT scans with complete imaging of the cranial base, maxilla, mandible, the first 4 cervical vertebrae (C1 - C4), and the associated airway. The exclusion criteria were (1) previous orthodontic treatment and/or orthognathic surgery, (2) A point-nasion-B point (ANB) angle $< 4^\circ$, (3) known syndromic conditions, (4) presence of pathology detectable along the upper airway, and (5) swallowing during scan acquisition.

After application of the inclusion and exclusion criteria, 67 patients were included in the final sample (Fig. 1).

2. Methods

1) CBCT image acquisition

All images were taken by the same operator using the same CBCT device (Alphard-3030; ASAHI Roentgen IND, Kyoto, Japan). The following specifications were used: tube voltage, 80 kVp; dose, 5.0 mA; scanning time, 17 seconds; voxel size, 0.39 mm as cranial mode. All patients were instructed to be seated upright and simultaneously fixed with the chin cup and ear rod to allow Frankfort horizontal to be positioned parallel to the floor. After the images were acquired, they were imported as digital imaging and communications in medicine (DICOM) files using the INFINITT PACS software program (INFINITT healthcare Co., Ltd, Seoul, Korea).

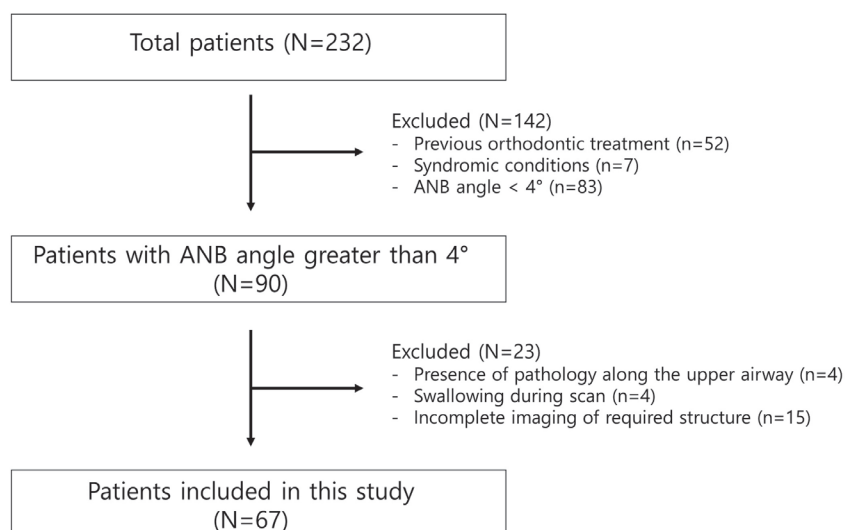


Fig. 1. Flow chart of patient selection.

2) Image preparation and airway assessment

3D images were reconstructed from the DICOM files using the OnDemand3D Application (Cybermed, Daejeon, Korea). All CBCT images were reoriented in all three planes according to the following guidelines[9]:

- (1) Coronal plane : orbitale of both sides were on the same horizontal plane.
- (2) Sagittal plane : Frankfort plane was horizontal.
- (3) Axial plane : a line through the crista galli and the basion was vertical.

The upper airway volume and minimal cross-sectional area were measured according to the guidelines set forth by Anan-

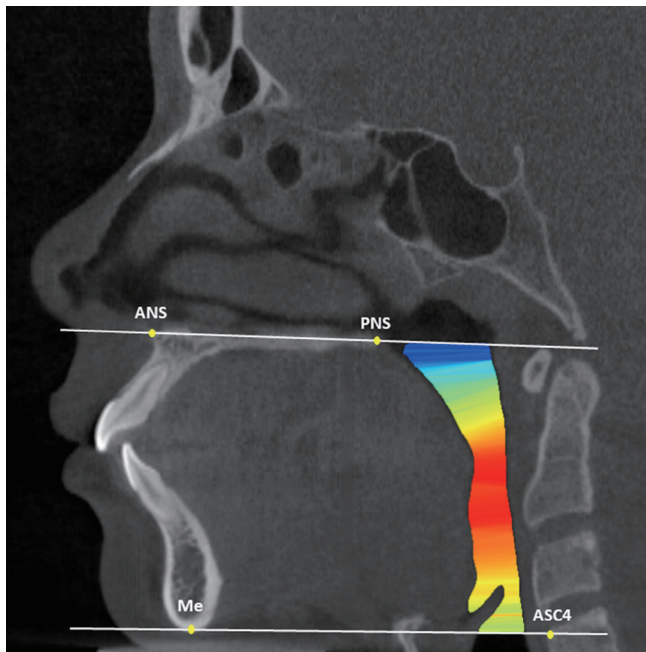


Fig. 2. Margins for upper airway assessment[9]. ANS = anterior nasal spine, PNS = posterior nasal spine, Me = menton, ASC4 = antero-superior edge of the fourth cervical vertebrae

darajah *et al.*[9] (Table 1, Fig. 2). The minimal cross-sectional area reflected the most constricted airway area within the defined margins.

3) Craniofacial morphology assessment

Craniofacial morphology was assessed on automatically constructed 2D lateral and posteroanterior cephalograms with no magnification. The images were imported into Vceph™ 6.0 (Osstem Implant, Seoul, Korea) for analysis. The following landmarks and measurements were used in this study:

(1) Landmarks (Fig. 3 and 4)

- ① Sella (S): The midpoint of sella turcica
- ② Nasion (N): The most anterior point on frontonasal suture
- ③ Orbitale (Or): The most inferior point on margin of orbit
- ④ Porion (Po): The most superior point of outline of external auditory meatus
- ⑤ Anterior nasal spine (ANS): The apex of the anterior nasal spine
- ⑥ Posterior nasal spine (PNS): The tip of the posterior nasal spine
- ⑦ A-point (A): The most posterior point on the anterior contour of the maxillary alveolar arch
- ⑧ B-point (B): The most posterior point on the anterior contour of the mandibular alveolar arch
- ⑨ Pogonion (Pg): The most anterior point on the mid-sagittal mandibular symphysis
- ⑩ Gonion (Go, lateral cephalogram): The most posterior inferior point on angle of mandible
- ⑪ Gonion (Go, posteroanterior cephalogram): The most lateral point on the convex margin on the angle of mandible
- ⑫ Maxillary notch (Mx): The intersection of the lateral contour of the maxillary alveolar process and the lower contour of the maxillo-zygomatic process of the maxilla

Table 1. Anatomical and technical limits of the upper airway[9]

Limit	Anatomical	Technical
Superior	Hard and soft palate	The line passing from the palatal plane (ANS to PNS) extending to the posterior wall of the pharynx
Inferior	Vallecula (plane of the hyoid bone; base of the epiglottis)	Line passing from the antero-superior edge of C4 to menton
Anterior	Circumvallate papillae and the oropharyngeal isthmus	Line passing from the soft palate to menton
Posterior	Respective pharyngeal walls	Posterior wall of the pharynx
Laterally	Respective pharyngeal walls	Respective pharyngeal walls

ANS = anterior nasal spine, PNS = posterior nasal spine, C4 = the fourth cervical vertebrae

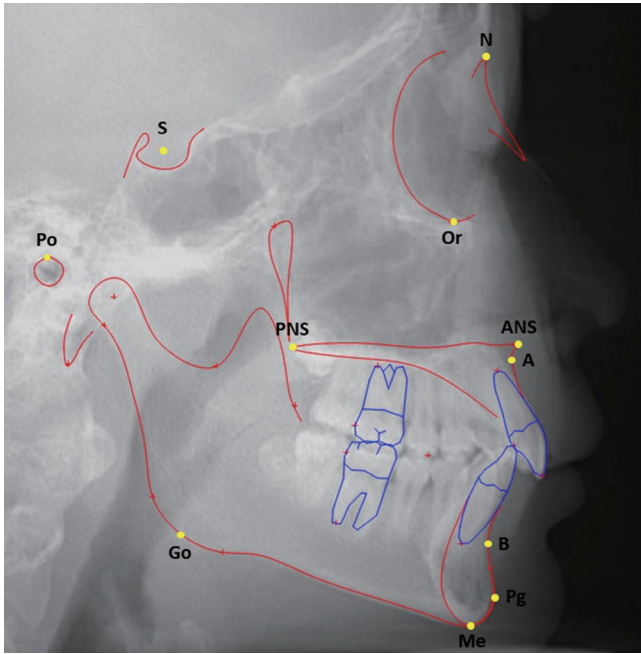


Fig. 3. Lateral cephalometric landmarks.

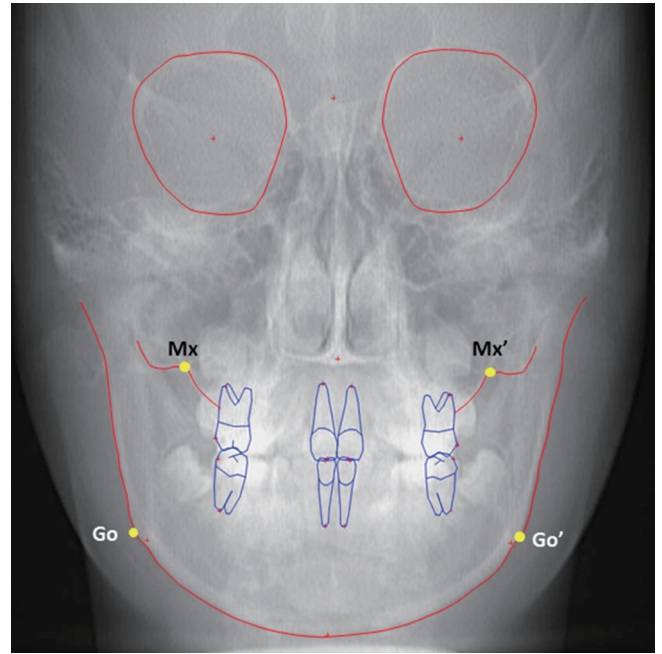


Fig. 4. Posteroanterior cephalometric landmarks.

(2) Vertical craniofacial dimensions (Fig. 5)

- ① Anterior facial height (AFH): The distance between N and Me
- ② Posterior facial height (PFH): The distance between S and Go
- ③ AFH/PFH: The ratio of AFH to PFH
- ④ Frankfurt-mandibular plane angle: The angle formed by the Frankfurt horizontal plane (Or-Po) and the mandibular plane (Go-Me)

(3) Sagittal craniofacial dimensions (Fig. 6)

- ① ANB: The difference between sella-nasion-A point and sella-nasion-B point
- ② Facial convexity: The angle formed by N, A, and Pg
- ③ A to N-perpendicular: The liner distance from A to N perpendicular
- ④ Pg to N-perpendicular: The liner distance from Pg to N perpendicular
- ④ Mandibular body length: The distance between Go and Me
- ⑤ Palatal length: The distance between ANS and PNS

(4) Transverse craniofacial dimensions (Fig. 7)

- ① Palatal width: The distance between Mx and Mx'
- ② Mandibular width: The distance between Go and Go'

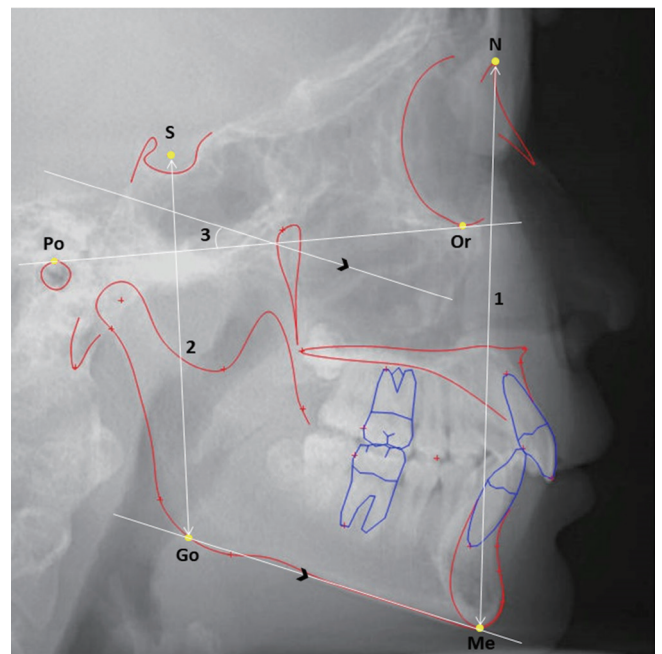


Fig. 5. Vertical craniofacial dimensions.

1 = AFH, 2 = PFH, 3 = FMA

4) Skeletal maturity assessment

Skeletal maturity was assessed on 2D lateral cephalograms using the Cervical Vertebral Maturation index according to Baccetti *et al.*[10] and categorized as corresponding to pre-peak, peak, and post-peak stages.

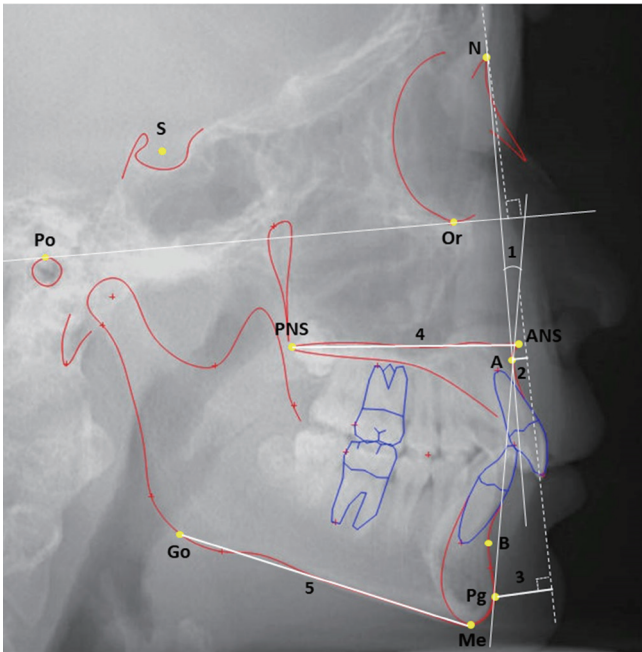


Fig. 6. Sagittal craniofacial dimensions.
 1 = Facial convexity, 2 = A to N-perpendicular, 3 = Pg to N-perpendicular, 4 = Palatal length, 5 = Mandibular body length

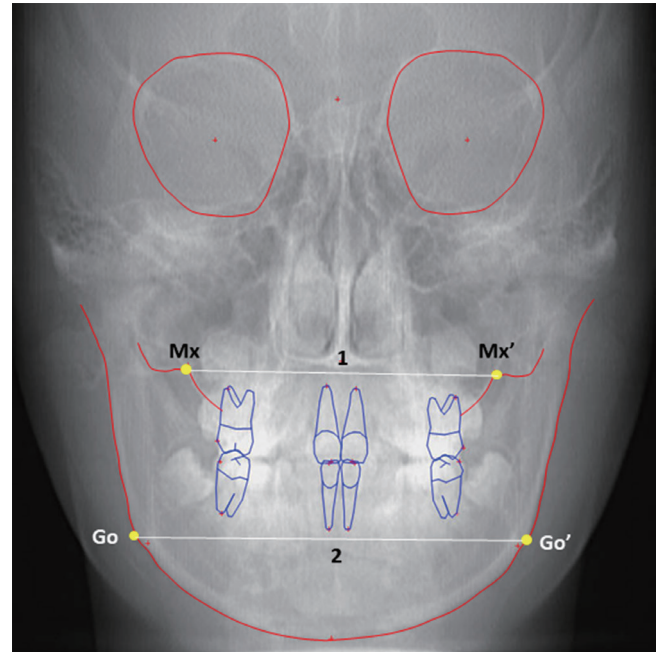


Fig. 7. Transverse craniofacial dimensions.
 1 = Palatal width, 2 = Mandibular width

5) Reliability

This study was conducted by one investigator, and after 4 weeks, 20 patients were randomly selected and remeasured. When the intraclass correlation coefficient (ICC) value was obtained for the measured values of upper airway dimensions and craniofacial morphology, all of them were found to be 0.9 or higher.

6) Statistical analysis

The normality of the distribution was assessed using the Kolmogorov-Smirnov test. Differences in the upper airway dimensions according to gender were analyzed using the Mann-Whitney test. Differences according to skeletal maturity were analyzed using one-way ANOVA followed by Bonferroni's Post Hoc test. Pearson's correlation test was performed to investigate the correlations between upper airway dimensions, age and craniofacial morphology. Partial correlation analysis was performed to eliminate the effects of age and skeletal maturity, and multiple regression analysis was performed to assess the most relevant variables for airway dimensions. All statistical analyses were conducted using Windows SPSS 25.0 (IBM, Armonk, NY, USA).

III. Results

Out of 67 patients, 37 (55.22%) were male and 30 (44.78%) were female. The mean age of the study population was 12.25 ± 2.11 years old. Based on skeletal maturity, 25.7% were in the pre-peak stage, 32.84% were in the peak stage, and 41.79% were in the post-peak stage (Table 2). The mean values for the craniofacial morphology and upper airway dimensions are presented in Table 3.

Gender was not significantly associated with airway volume or minimal cross-sectional area (Table 4). There was a statistically significant difference in the upper airway dimensions according to skeletal maturity. Airway volume increased from pre-peak stage to post-peak stage and showed statistically significant differences between the groups (Fig. 8). The minimal cross-sectional area also increased from pre-peak stage to post-peak stage. No statistically significant differences between pre-peak and peak stages were identified (Fig. 9). Airway volume and minimal cross-sectional area were positively correlated with age ($p = 0.000$).

The partial correlation analysis adjusting for age and skeletal maturity revealed significant associations between upper air-

Table 2. Patients' demographic factors

Characteristic	
Gender	n (%)
Male	37 (55.22)
Female	30 (44.78)
Age	Year
Mean ± SD	12.25 ± 2.11
Skeletal maturity	n (%)
Pre-peak	17 (25.37)
Peak	22 (32.84)
Post-peak	28 (41.79)

SD = standard deviation

way dimensions and vertical, sagittal, and transverse craniofacial morphology. Airway volume was positively associated with AFH, PFH, mandibular body length, maxillary and mandibular width (Table 5). The minimal cross-sectional area was positively associated with AFH, mandibular body length, and mandibular width and negatively associated with ANB and facial convexity (Table 6).

Tables 7 and 8 show the results of multiple regression analysis on upper airway dimensions and variables with confirmed correlation. Upper airway volume showed the highest associations with AFH and age ($r^2 = 0.502$). The variables that showed the highest associations with the minimum cross-sectional area were the mandibular width and age ($r^2 = 0.544$).

Table 3. The maximum, minimum, mean and standard deviation of measurements

Variables	Minimum	Maximum	Mean	SD
Upper airway dimensions				
Airway volume (cc)	3.32	28.05	15.63	6.19
Minimal cross-sectional area (mm ²)	24.64	353.41	156.84	73.85
Craniofacial morphology				
Vertical dimension				
AFH (mm)	103.60	134.53	114.95	7.39
PFH (mm)	62.30	90.62	74.73	6.54
AFH/PFH	1.28	1.90	1.55	0.12
FMA (°)	14.82	45.21	30.39	6.46
Sagittal dimension				
ANB (°)	4.00	11.05	6.22	1.43
Facial convexity (°)	5.25	22.78	11.68	3.39
A to N perpendicular (mm)	-10.40	6.69	-0.72	3.19
Pg to N perpendicular (mm)	-9.99	22.65	8.34	6.05
Palatal length (mm)	40.95	54.98	47.96	3.42
Mandibular body length (mm)	70.59	90.52	80.77	5.43
Transverse dimension				
Palatal width (mm)	79.17	101.48	90.17	5.24
Mandibular width (mm)	76.71	105.09	89.88	6.42

SD = standard deviation

Table 4. Upper airway dimensions according to gender

		Airway Volume (cc) (Mean ± SD)	<i>p</i> value	Minimum Cross-sectional Area (mm ²) (Mean ± SD)	<i>p</i> value
Pre-peak	Male	9.57 ± 4.29	0.257	93.50 ± 57.41	0.854
	Female	7.48 ± 1.02		96.56 ± 10.55	
Peak	Male	16.55 ± 4.25	0.283	152.11 ± 61.46	0.250
	Female	14.04 ± 2.90		124.19 ± 42.47	
Post-peak	Male	21.87 ± 3.60	0.137	224.15 ± 60.13	0.164
	Female	19.61 ± 4.45		198.79 ± 63.13	

p value from Mann-Whitney test

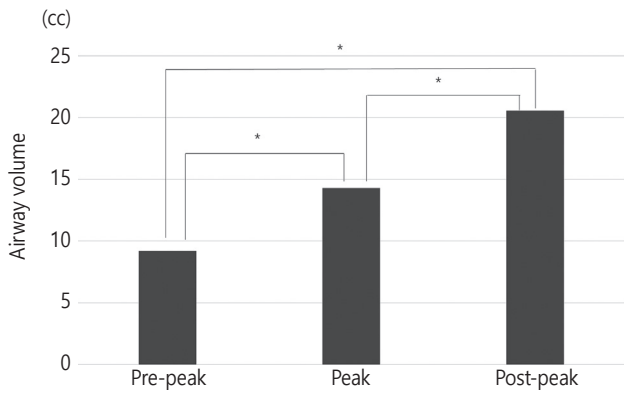


Fig. 8. Airway volume in relation to skeletal maturity. Bonferroni's Post Hoc test (* : $p < 0.05$)

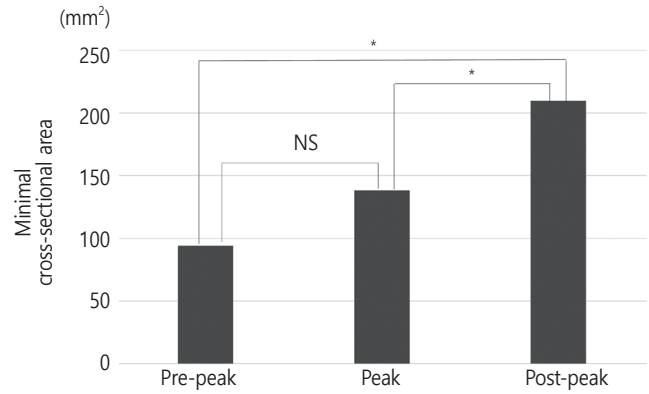


Fig. 9. Minimal cross-sectional area in relation to skeletal maturity. Bonferroni's Post Hoc test (* : $p < 0.05$, NS = not significant)

Table 5. Partial correlation between airway volume and craniofacial morphology

	Airway Volume	
	Correlation coefficient	p value
Vertical dimension		
AFH	0.461	0.000
PFH	0.292	0.018
AFH/PFH	-0.005	0.970
FMA	-0.003	0.981
Sagittal dimension		
ANB	-0.213	0.081
Facial convexity	-0.235	0.060
A to N perpendicular	0.040	0.751
Pg to N perpendicular	0.061	0.628
Palatal length	0.206	0.100
Mandibular body length	0.245	0.049
Transverse dimension		
Palatal width	0.284	0.022
Mandibular width	0.437	0.000

Partial correlation test
Control variable : age, skeletal maturity

Table 6. Partial correlation between minimal cross-sectional area and craniofacial morphology

	Minimal Cross-sectional Area	
	Correlation coefficient	p value
Vertical dimension		
AFH	0.364	0.003
PFH	0.134	0.287
AFH/PFH	-0.110	0.383
FMA	-0.043	0.735
Sagittal dimension		
ANB	-0.265	0.033
Facial convexity	-0.399	0.001
A to N perpendicular	0.032	0.798
Pg to N perpendicular	-0.025	0.846
Palatal length	0.167	0.183
Mandibular body length	0.316	0.010
Transverse dimension		
Palatal width	0.178	0.157
Mandibular width	0.529	0.000

Partial correlation test
Control variables : age, skeletal maturity

Table 7. Multiple regression analysis of the airway volume with independent variables

Independent Variables	Airway Volume			
	B	β	t	p value
(constant)	42.401			
AFH	0.393	0.469	4.665	0.000
Age	1.050	0.358	3.566	0.001

Multiple regression analysis
B = Unstandardized coefficients, β = Standardized coefficients

Table 8. Multiple regression analysis of the minimal cross-sectional area with independent variables

Independent Variables	Minimal Cross-sectional Area			
	B	β	t	p value
(constant)	-513.281			
Mandibular width	5.953	0.517	5.054	0.000
Age	11.022	0.315	3.081	0.003

Multiple regression analysis
B = Unstandardized coefficients, β = Standardized coefficient

IV. Discussion

Growth and function of the upper airway space are closely associated with maxillofacial growth[11]. The upper airway dimensions have been reported to be influenced by posture, gender, age, obesity, and body mass index[12-14]. Growth-related and anatomical factors can be easily assessed using general orthodontic diagnostic data. It is clinically relevant to investigate which of these factors are most highly associated with upper airway dimension.

The importance and reliability of ANB angle are still controversial[15]. However, it is a commonly used cephalometric parameter in clinical orthodontics[16]. The ANB angle and the angle of convexity in the pre-pubertal assessment showed a high prediction accuracy for post-pubertal jaw relationships[17]; in this study, the ANB angle was used as the scale reflective of the sagittal relationship of the maxilla and mandible.

Anatomical structures vary with growth and development. There exist differences in upper airway assessment between adults and children[18]. In studies where 3D analyses of upper airways were performed in children, there was either a lack of airway delineation according to anatomical boundaries in children[19,20], and/or easily mobile soft-tissue landmarks were used[5,21]. Anandarajah *et al.*[9] proposed new reliable and reproducible upper airway margins to be used on CBCT scans of children for the assessment of upper airway dimensions.

Most of the studies on upper airway dimensions reported no gender differences[3,4,6,22]. There was no statistically significant gender difference in the airway dimensions in this study. In contrast, Alves *et al.*[23] reported gender differences in the retropalatal and retrolingual regions in patients with Class III malocclusion. Chiang *et al.*[24] reported that boys not only had a longer and larger airway than girls but also experienced a faster increase in dimensions.

In this study, upper airway dimensions increased from 8 to 15 years of age and showed a positive correlation with age. This finding is in agreement with the report by Schendel *et al.*[25], who reported that airway dimensions consistently increased until about 20 years of age. Chiang *et al.*[24] found that the upper airway dimensions increased during a rapid period of craniofacial growth in patients between the ages of 8 and 18 years.

Although the walls of the upper airway are constructed of soft tissue structures that influence the luminal size, the cra-

niofacial osseous structures determine the general size of the upper airways[18]. Skeletal maturity is closely associated with upper airway dimensions in children. It was found that upper airway dimensions were smallest in patients before pubertal growth, and there was statistically significant differences between growth stages[22,26]. In this study, the upper airway dimensions also increased during growth. These dimensional airway changes in relation to skeletal maturity could reflect the growth-related changes of bony structures surrounding the upper airways. There may be differences in skeletal maturity among the pre-peak, peak, and post-peak groups; future studies will be needed to address such issues.

Many studies have reported the association between sagittal craniofacial dimensions and the upper airway space, with the upper airway space showing a negative correlation with the sagittal intermaxillary relationship[3-6,22]. Just as in previous studies, this study found that upper airway volume and the minimum cross-sectional area were negatively correlated with ANB and facial convexity. However, only the minimum cross-sectional area showed a statistically significant correlation. This may be because this study was conducted in skeletal Class II patients, which makes the range of ANB and facial convexity were not significantly dissimilar. Mandibular body length showed a statistically significant correlation with upper airway volume, which was also confirmed in previous studies[3,27].

In relation to vertical craniofacial dimensions, correlations have been found between upper airway dimensions and anterior facial height. This is consistent with the findings of previous studies[3,27]. This indicates that patients with vertical growth patterns with a large anterior facial height are likely to have an expanded airway. However, there were several studies that reported diverse relationships between upper airway dimensions and vertical growth patterns[28,29]. This difference may be due to the fact that there was variability within the study population, and the variables used to assess vertical craniofacial morphology patterns were different from those used in previous studies.

This study identified the association between transverse craniofacial morphology and upper airway dimensions. Maxillary width was found to be positively correlated with upper airway volume. Mandibular width was found to be positively correlated with upper airway volume and the minimum cross-sectional area. Anandarajah *et al.*[22] reported that mandibular width was significantly correlated with upper airway volume and the minimum cross-sectional area, and that growing pa-

tients with a large sagittal intermaxillary relationship and narrow mandibular width are particularly at risk of having narrow upper airway dimensions. In contrast, Di Carlo *et al.*[30] found no association between upper airway dimensions and craniofacial morphology in all three planes. This discrepancy may be explained by the fact that the patients were scanned in the supine position and the population sample of this study were older than those in other studies.

This study conducted a multiple regression analysis using factors associated with upper airway dimensions. The airway volume was found to have the strongest association with AFH and age. The minimum cross-sectional area was found to have the strongest association with mandibular width and age.

The limitations of this study were that sample size was small and other functional factors influencing the upper airway space were not considered. More comprehensive investigations and large-scale studies should be carried out in the future to overcome the limitations of the present study. Nonetheless, this study conducted a multifactorial analysis of the upper airway dimensions and verified that upper airway dimensions in skeletal Class II children and adolescents were associated with age, skeletal maturity, and craniofacial morphology in all three planes.

V. Conclusion

This study was conducted to investigate factors influencing the upper airway dimensions in skeletal Class II children and adolescents using CBCT images. Upper airway space did not show gender differences, but showed significant associations with age, skeletal maturity, and craniofacial morphology in all three planes. In skeletal Class II children and adolescents, the risk of a reduced upper airway space is higher in those who are younger and have smaller anterior facial height and mandibular width.

Authors' Information

Byounghwa Kim <https://orcid.org/0000-0002-5606-4869>

Jewoo Lee <https://orcid.org/0000-0001-9640-4752>

Jiyoung Ra <https://orcid.org/0000-0002-2569-3259>

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국문초록

골격성 Ⅱ급 소아·청소년의 상기도 공간에 영향을 미치는 요인 : CBCT 연구

김병화¹ · 이제우² · 라지영²

¹ 원광대학교 치과대학 소아치과학교실

² 원광대학교 치과대학 소아치과학교실 및 치의학교육연구센터

이 연구의 목적은 골격성 2급 부정교합 소아·청소년의 상기도 공간을 분석하고, 이에 영향을 미치는 요인을 알아보고자 함이다.

총 67명의 골격성 2급 소아·청소년의 CBCT영상으로 연구를 진행하였다. 상기도 부피와 최소 단면적은 3차원 CBCT 영상을 통해 평가하였으며, 악안면 형태와 골 성숙도는 2차원 두부방사선사진을 통해 평가하였다. 상기도 부피 및 최소 단면적과 다양한 변수들간의 연관성이 분석되었다.

상기도 공간은 최대 성장기 이전의 환자에서 가장 작았으며, 연령과 양의 상관관계를 보였다. 상기도 부피는 전안면 고경 및 연령과, 최소 단면적은 하악 폭경 및 연령과 가장 높은 상관관계를 나타냈다.

골격성 2급 소아·청소년의 상기도 공간은 연령, 골 성숙도, 세 평면에서의 악안면 형태와 유의한 연관성을 가졌다.