BMC Oral Health

RESEARCH

Open Access

The hyoid bone position and upper airway morphology among children with and without adenotonsillar hypertrophy: a cross-sectional study

Yaqi Li[1,2†], Susu Yi[1,2†], Jun Zhang[3], Fang Hua[1,4,5,6,7], Tingting Zhao[1,2,4,7*] and Hong He[1,2,4,7*]

Abstract

Background Adenotonsillar hypertrophy (ATH) is a major cause of pediatric obstructive sleep apnea (OSA), potentially impacting craniofacial growth and development. Currently, whether children with ATH exhibit distinctive hyoid bone position and upper airway morphology remains uncertain. This research aimed to compare the hyoid bone position and upper airway morphology of children with and without ATH.

Methods A total of 199 children aged 6–8 years were recruited for the study, and their pre-treatment lateral cephalograms were obtained. The size of the adenoids and tonsils on the lateral cephalogram was assessed based on Fujioka's and Baroni's methods for classification into groups: adenoid hypertrophy only (AHO) group, tonsillar hypertrophy only (THO) group, adenoid and tonsillar hypertrophy (AH + TH) group, and control group (CG). The position of the hyoid bone and upper airway morphology was analyzed using Dolphin Image Software.

Results The distance between the hyoid bone and mentum was greater in the THO group compared to the AHO group ($P = 0.005$). Children in the AHO group exhibited a longer soft palate (SPL) compared to the THO group ($P = 0.014$), whereas the THO group displayed a reduced SPL in comparison to healthy controls ($P = 0.008$). The THO group showed a more inferior tongue position compared to children in the AHO group ($P = 0.004$). Subjects in the THO group exhibited significantly wider inferior airway space compared to healthy children ($P < 0.001$).

Conclusions Adenotonsillar hypertrophy may be associated with hyoid bone position and upper airway morphology in children seeking for orthodontic treatment. In children with enlarged tonsils, the hyoid bone was positioned farther from the mentum than in those with enlarged adenoids. Conversely, children with enlarged adenoids had a longer soft palate compared to those with enlarged tonsils.

Keywords Adenotonsillar hypertrophy, Hyoid bone, Upper airway, Lateral cephalogram

†Yaqi Li and Susu Yi contributed equally to this work.

*Correspondence:
Tingting Zhao
zhaott1991@whu.edu.cn
Hong He
drhehong@whu.edu.cn

Full list of author information is available at the end of the article

Background

Adenoids and tonsils are lymphoid tissues situated within the pharynx, forming a principal part of Waldeyer's ring and play a crucial role in the local immune defense of the oral and upper respiratory tracts [1]. The adenoids, located on the posterior wall of the nasopharynx, are typically larger in children but may regress during adolescence [2]. The tonsils, positioned bilaterally within the oropharynx, share a similar lymphoid composition and function similarly in pathogen capture and processing [3].

In addition to infectious causes, various non-infectious factors, including allergies, can contribute to the hypertrophy of adenoids or tonsils, leading to obstruction in the nasopharynx or oropharynx, respectively [4]. Adenotonsillar hypertrophy (ATH) in children is a significant medical concern that often leads to obstructive sleep apnea (OSA), disturbed sleep patterns, and potential alterations in craniofacial growth [5]. These conditions may induce adaptive changes in the hyoid bone position and upper airway morphology [6]. However, the extent to which these changes are characteristic of ATH remains unclear.

The hyoid bone, a mobile structure within the neck, plays a vital role in maintaining upper airway patency and is crucial for functions including respiration, swallowing, and speech [7–9]. Investigating its position may provide important insights into airway obstruction mechanisms. In children with adenotonsillar hypertrophy (ATH), it is unclear whether they display distinct variations in hyoid bone position compared to healthy children or if they develop compensatory anatomical changes to address upper airway obstruction. These aspects remain underexplored in the existing literature.

While nasopharyngeal endoscopy is the common diagnostic methods for adenotonsillar hypertrophy, our study employs lateral cephalogram—a commonly used diagnostic tool in orthodontic clinics. Lateral cephalogram provides reliable accuracy for evaluating adenoids sizes [10], which enable us to identify potential upper airway risks that may have an impact on overall health, rather than solely focusing on malocclusion.

This cross-sectional study aimed to delineate the distinct characteristics of the hyoid bone position and upper airway morphology among children with and without ATH. The patients were classified into four distinct groups: adenoid hypertrophy, tonsillar hypertrophy, adenoid-tonsil hypertrophy, and healthy controls. This classification enables a detailed examination of how obstructions at different airway points affect overall airway morphology and hyoid bone position. By focusing on pre-adolescent children aged 6–8 years, the study minimizes potential bias from physiological adenoid and tonsil atrophy that occurs in older individuals. The results will provide valuable insights for orthodontics, particularly in the clinical and multidisciplinary management of patients with ATH. The null hypothesis posits no significant association between ATH and the position of the hyoid bone or upper airway morphology.

Methods

Ethical approval

The study protocol was reviewed in accordance with the principles outlined in the Helsinki Declaration [11]. This study was conducted following the research guidelines of Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) [12].The Ethics Committee of Stomatology Hospital of Wuhan University approved this cross-sectional study (Approval number: WDKQ2024-B45).

Sample description

Children admitted to the Orthodontics Department of Stomatology Hospital of Wuhan University were consecutively recruited from June 2023 to December 2023. The inclusion criteria were: (1) age range of 6–8 years; (2) routine lateral cephalograms obtained before treatment. Exclusion criteria included: (1) unclear lateral cephalograms that hindered the accurate identification of the anatomic position of the hyoid bone and morphological characteristics of the upper airway; (2) history of severe craniomaxillofacial trauma and orthodontic treatment; (3) cleft lip and palate, syndromes, or systemic diseases; (4) previous adenotonsillectomy; (5) acute inflammation related to adenoids or tonsils. The patients' lateral cephalograms were acquired along with vital demographic data, including gender, age, and health status.

Sample size calculation

The minimum sample size required for this study was calculated using G*Power software (version 3.1.9.7). The estimated effect size was based on the distance between the hyoid bone and retrognathion among different groups in previous studies (effect size = 0.3501) [13]. The test power (1-β) was set at 0.95, the significance level (α) was established at 0.05, and a total of four groups were involved. Consequently, the minimum total sample size needed for this study was determined to be 148.

Cephalometric analysis

All lateral cephalograms were taken using the same cephalostat (OP200D Soredex, Instrumentarium, Finland), with the patient positioned in a natural head posture and maintaining the lips in a relaxed state. Prior to the procedure, the patients were instructed about the potential impact of swallowing on the lateral cephalograms and instructed to refrain from swallowing during the X-ray procedure. Dolphin Image Software (version 11.95, Dolphin Imaging & Management Solutions, Chatsworth, Calif.) was utilized as the tool for cephalometric measurement. The cephalometric variables analyzed in our study were determined by referring to previous studies on hyoid bone position and upper airway morphology [14–16]. The definition and schematic diagram of the cephalometric landmarks and variables utilized in this study are presented in Table 1 and Fig. 1.

Assessment of adenoid and tonsil sizes

The diagnoses of adenoid hypertrophy and tonsil hypertrophy were developed based on Fujioka's and Baroni's methods, as well as the experience of our research team [17–19]. Fujioka's method, widely employed for assessing adenoid hypertrophy, has been validated with 95% specificity and a 94% positive predictive value [20]. Similarly, Baroni's method for evaluating tonsillar hypertrophy has shown strong overall accuracy (AUC: 0.90) [21]. The reference points and lines used for adenoid and tonsil measurements on the lateral cephalogram are depicted in Fig. 2. The degree of adenoid or tonsillar obstruction in the pharyngeal airway space was calculated using the formulas: (A/N)×100% and (Oa-To/Oa-Op)×100%. If the resulting percentage exceeded 50%, this indicates hypertrophy of the adenoids and/or tonsils. After measuring the size of the adenoids and tonsils using lateral cephalograms, patients were categorized into four groups based on the extent of hypertrophy: adenoid hypertrophy only (AHO), tonsillar hypertrophy only (THO), adenoid and tonsillar hypertrophy (AH+TH), and control group (CG). Representative lateral cephalograms for each group are presented in Fig. 3.

Quality control and evaluation of the error

All cephalometric measurements were conducted by a proficient orthodontist graduate student (Y.L.), who received systematic training in the software prior to commencing measurements. After the initial measurements, 20 samples were randomly selected by the same researcher for re-measurement after a one-month interval. The Intraclass Correlation Coefficient (ICC) was employed to assess the consistency of measurement

Table 1 Definition of hyoid bone position and upper airway morphology variables used in this study

Measurements	Definition
Hyoid bone position	
Hy-C3 (mm)	Distance between Hy point and C3 point: Indicates the position of the hyoid bone in relation to the cervical vertebra.
Hy-Me (mm)	Distance between Hy point and Me point: Indicates the position of the hyoid bone in relation to the mentum.
Hy-RGn (mm)	Distance between Hy point and RGn point: Indicates the position of the hyoid bone in relation to the mentum.
C3-RGn (mm)	Distance between C3 point and RGn point: Indicates the position of the mentum in relation to the cervical vertebra.
Hy-S (mm)	Distance between Hy point and S point: Indicates the position of the hyoid bone in relation to the cranial base.
Hy to SN (mm)	Distance from Hy point to SN plane: Indicates the position of the hyoid bone in relation to the cranial base.
Hy to MP (mm)	Distance from Hy point to mandibular plane (Go-Me): Indicates the vertical position of the hyoid bone.
Go-Hy-Me (°)	Angle formed by the Go-Hy line and Hy-Me line: Indicates the vertical position of the hyoid bone.
Soft palate	
SPL (mm)	Length of soft palate: Quantified as the linear distance between the PNS point and U point.
SPT (mm)	Thickness of soft palate: Refers to the maximum thickness of the soft palate measured along a line perpendicular to the PNS-U line.
U-PTV (mm)	Distance from U point to PTV line.
SPA (°)	Soft palate angle: Formed by the ANS-PNS line and the PNS-U line, indicating the angular orientation of the soft palate.
Tongue	
TGL (mm)	Tongue length: Quantified as the linear distance between the V point and T point.
TGH (mm)	Tongue height: Refers to the maximum height measured along a perpendicular line to the V-T line at the dorsum of the tongue.
Td to PP (mm)	Minimum distance along perpendicular line from tongue dorsum (Td) to palatal plane (ANS-PNS): Indicates the spatial relationship between the tongue dorsum and the palatal plane.
T-PTV (mm)	Distance from T point to PTV line.
Airway	
PNS-AD1 (mm)	Distance from PNS point to the adenoid tissue surface: Measured along a line connecting the PNS point and Ba point.
PNS-AD2 (mm)	Distance from PNS point to the adenoid tissue surface: Measured along a line perpendicular to the S-Ba plane.
UAS (mm)	Upper airway space: Quantified as the linear distance from the U point to the posterior pharyngeal wall along a line parallel to the Go-B line.
IAS (mm)	Inferior airway space: Quantified as the linear distance between the posterior pharyngeal wall and the dorsum of the tongue, measured along a line connecting the Go point and B point.
V-LPW (mm)	Vertical distance from the V point to the posterior pharyngeal wall.
VAL (mm)	Vertical length of the airway: Quantified as the linear distance between the PNS point and the V point.

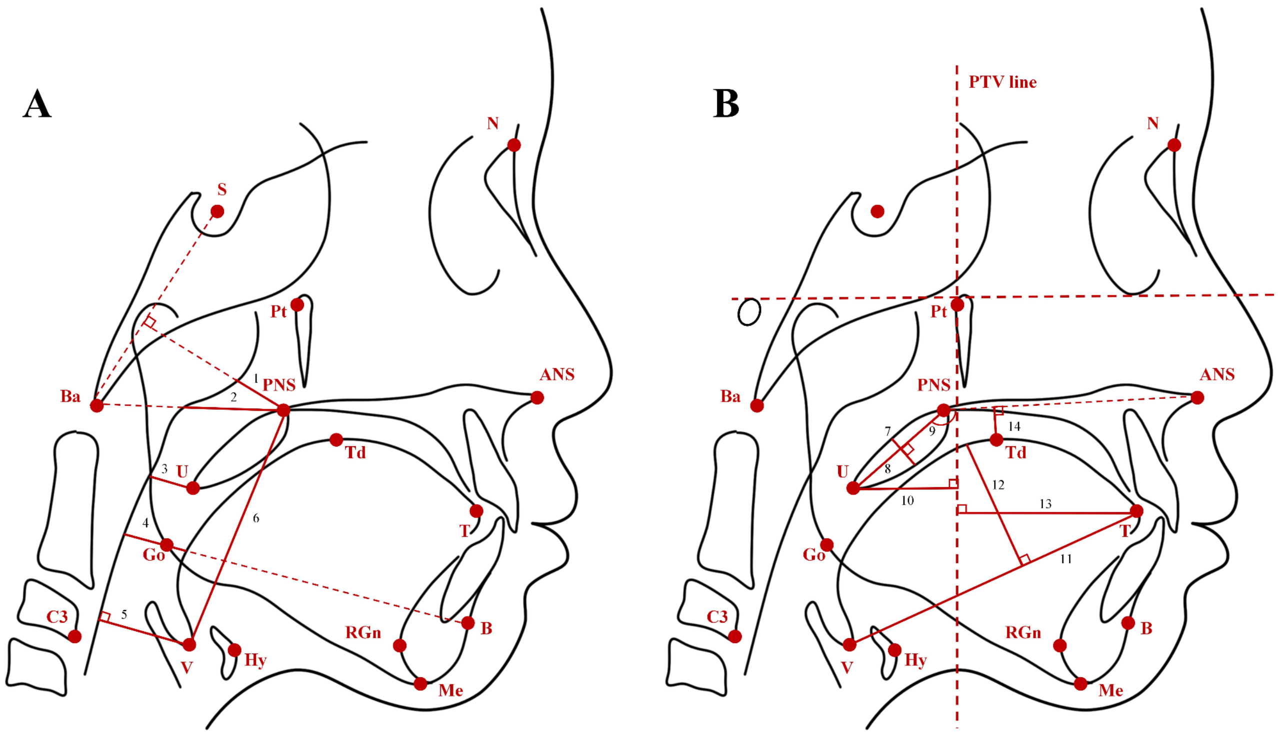

Fig. 1 Cephalometric landmarks, upper airway, soft palate and tongue parameters used in this study. ***Cephalometric landmarks***. N: nasion; S: sella; Pt: pterygoid; Ba: basion; PNS: posterior nasal spine; ANS: anterior nasal spine; Td: tongue dorsum; U: tip of uvula; T: tip of tongue; Go: gonion; B: supramental; C3: most anterior and inferior point of the third cervical vertebra; V: vallecula epiglottica; Hy: most anterior and superior point on the body of the hyoid bone; RGn: most protrusive point of retrognathion; Me: menton; PTV line: a line perpendicular to FH plane through the Pt point. Figure 1**A**. ***Upper airway*** (1) PNS-AD2; (2) PNS-AD1; (3) UAS; (4) IAS; (5) V-LPW; (6) VAL. Figure 1**B**. ***Soft palate*** (7) SPT; (8) SPL; (9) SPA; (10) U-PTV. ***Tongue*** 11. TGL; 12. TGH; 13. T-PTV 14.Td-PP

results. The ICC value greater than 0.8 indicated excellent consistency. If the ICC > 0.8, statistical analysis would be performed on the initially measured data. Angular and linear measurement errors were assessed using the method of moments estimator (MME) formula [22].

Data analysis

Statistical analysis of the data was conducted using SPSS software (version 21.0; IBM, Armonk, NY). Continuous variables were presented as mean ± standard deviation, while categorical variables were expressed as n (%). The Shapiro-Wilk test was employed to assess the normal distribution of the data. In cases where the data met both normal distribution and homogeneity of variance assumptions, one-way ANOVA was utilized for inter-group comparisons; otherwise, the Kruskal-Wallis test was applied. Pairwise multiple comparisons were conducted using the Bonferroni method. Sex distribution among different groups was assessed using the Chi-square test. Significance was set at $P < 0.05$.

Results

The demographic profiles of participants are summarized in Table 2. After applying the previously mentioned inclusion and exclusion criteria, a total of 199 children were enrolled in this study. Among them, 44 (17 boys, 27 girls; mean age: 7.30 ± 0.80) had enlarged adenoids, 39 (18 boys, 21 girls; mean age: 7.38 ± 0.63) had enlarged tonsils, 78 (35 boys, 43 girls; mean age: 7.10 ± 0.73) had both enlarged adenoids and tonsils, and the remaining 38 children (18 boys, 20 girls; mean age: 7.00 ± 0.74) were classified as healthy controls. Statistical analysis using the Chi-square test and Kruskal-Wallis test revealed no significant differences in terms of age ($P = 0.061$) and gender distribution ($P = 0.854$) among the different groups.

The measurement error ranged from 0.49° to 0.77° for angular measurements and 0.65 to 0.89 mm for linear measurements. The ICC values of the initial and subsequent measurements ranged from 0.87 to 0.96, indicating a high level of consistency. The initial measurements were subjected to statistical analysis as agreed upon in the methodology. The results of the one-way ANOVA or Kruskal-Wallis test revealed significant differences in hyoid bone position parameters, specifically Hy-Me ($P = 0.007$), Hy-RGn ($P = 0.005$), and C3-RGn ($P = 0.004$), among the four groups. In contrast, no statistically significant differences were found in the variables of Hy-C3 ($P = 0.448$), Hy-S ($P = 0.511$), Hy to SN ($P = 0.519$), Hy to MP ($P = 0.746$), and Go-Hy-Me angle ($P = 0.806$).

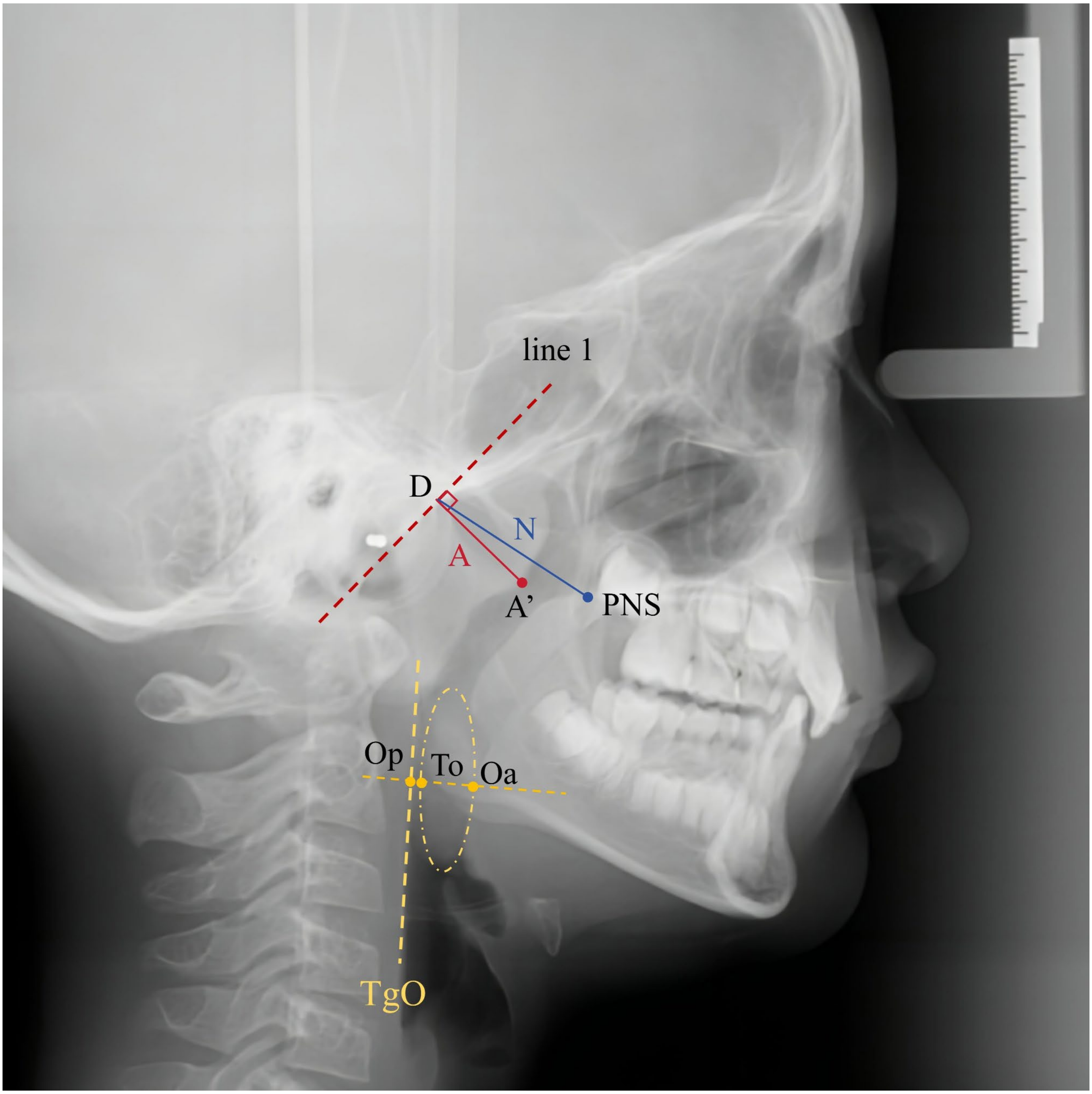

Fig. 2 Cephalometric landmarks and reference lines for adenoid and tonsil measurement. ***Landmarks*** A′: the maximal convexity along inferior margin of adenoid; PNS: posterior nasal spine; D: the line perpendicular to line 1 and passing through A′ point intersects line 1 at D point; To (Tonsillar point): the nearest point on the posterior outline of tonsil shadow to the posterior wall of the oropharynx; Op (Oropharynx posterior): the line passing through To point is perpendicular to TgO line and intersects the TgO line at Op point. Oa (Oropharynx anterior): the line perpendicular to the TgO passing through To point intersects the posterior outline of the tongue at Oa point. ***Reference lines*** line 1: the straight section of the anterior margin of the basiocciput; A: the line segment connecting A′ point and D point; N: the line segment connecting PNS point and D point; TgO (Tangent oropharynx): tangent line to the posterior wall of the oropharynx

We investigated the differences in the soft palate, tongue, and sagittal width of the airway among four groups to precisely characterize the morphological attributes of the upper airway. For the soft palate, the SPL ($P<0.001$) and U-PTV ($P<0.001$) parameters revealed statistically significant differences, while SPT ($P=0.158$) and SPA ($P=0.069$) did not. The tongue-related parameters, specifically Td to PP ($P=0.004$) and T-PTV ($P<0.001$), also revealed statistically significant differences among the groups. Whereas, no significant difference was observed in TGL ($P=0.469$) and TGH ($P=0.058$). The sagittal airway width, specifically VAL

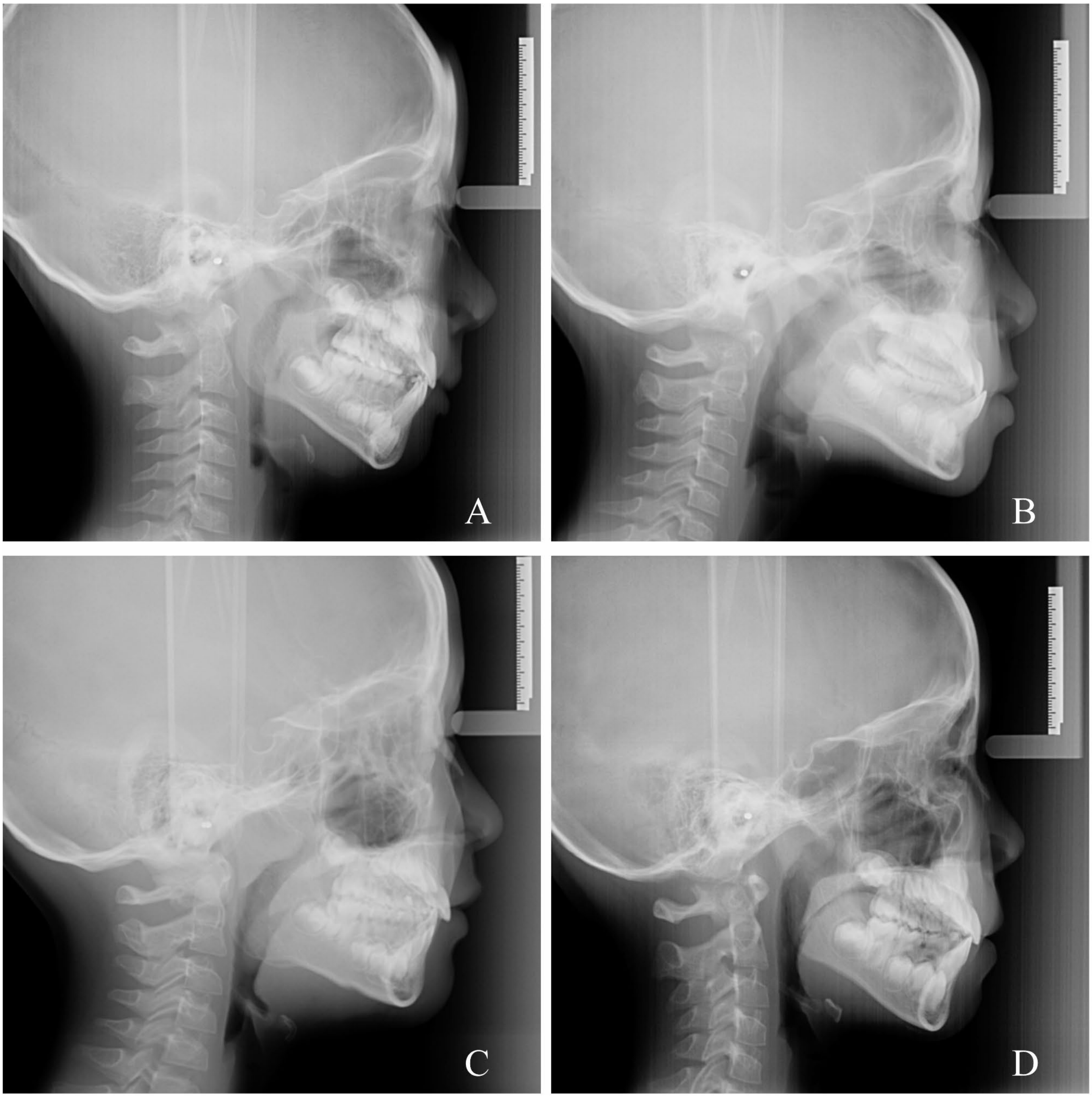

Fig. 3 Adenotonsillar hypertrophy observed in lateral cephalogram. (A) adenoid hypertrophy only; (B) tonsillar hypertrophy only; (C) adenoid and tonsillar hypertrophy; (D) No adenotonsillar hypertrophy

(P=0.142), showed no statistically significant difference, while the remaining five airway parameters demonstrated significant statistical disparities (P<0.001). The mean and standard deviation of all cephalometric parameters, along with the statistical analysis results for the four groups, are presented in Table 2.

The parameters exhibiting statistically significant differences were subjected to pairwise comparisons. The P-values for pairwise comparisons are shown in Table 3. Our findings indicated that children in the THO group had larger Hy-Me, Hy-RGn, and C3-RGn values than the AHO group, suggesting an increased distance between the hyoid bone and the mentum, as well as between the mentum and cervical vertebra. For the parameters related to the soft palate, we observed that the AHO group had a longer soft palate than the THO group, while children in the THO group displayed a shorter soft palate length compared to healthy controls. Additionally, the AHO group had a greater distance between the tip of the soft palate and the PTV line compared with the THO group.

Table 2 Comparisons of demographics and cephalometric variables among different groups

	AHO (*n* = 44)	THO (*n* = 39)	AH + TH (*n* = 78)	CG (*n* = 38)	*P* value
Demographics					
Age (years)	7.30 ± 0.80	7.38 ± 0.63	7.10 ± 0.73	7.00 ± 0.74	0.061[b]
Male sex, n (%)	17 (38.6)	18 (46.2)	35 (44.9)	18 (47.4)	0.854[c]
Hyoid bone position					
Hy-C3 (mm)	27.76 ± 3.31	28.51 ± 2.29	28.17 ± 2.60	27.55 ± 2.63	0.448[b]
Hy-Me (mm)	30.21 ± 5.58	34.00 ± 5.34	31.32 ± 4.52	32.00 ± 5.12	**0.007**[a]
Hy-RGn (mm)	24.36 ± 5.39	28.14 ± 4.85	25.49 ± 4.52	26.21 ± 4.93	**0.005**[a]
C3-RGn (mm)	50.96 ± 6.51	55.68 ± 6.36	52.93 ± 5.19	53.06 ± 5.19	**0.004**[a]
Hy-S (mm)	83.29 ± 6.27	83.76 ± 6.29	84.77 ± 5.98	84.88 ± 5.91	0.511[a]
Hy to SN (mm)	83.04 ± 6.23	83.44 ± 6.27	84.49 ± 5.96	84.55 ± 5.83	0.519[a]
Hy to MP (mm)	8.83 ± 4.53	9.66 ± 4.11	9.20 ± 3.62	9.62 ± 3.74	0.746[a]
Go-Hy-Me (°)	144.78 ± 16.98	142.40 ± 14.84	143.80 ± 13.44	142.00 ± 13.89	0.806[a]
Soft palate					
SPL (mm)	26.74 ± 2.08	25.02 ± 2.72	25.33 ± 2.67	26.90 ± 2.47	< **0.001**[a]
SPT (mm)	7.01 ± 1.17	7.50 ± 1.23	7.32 ± 0.99	7.42 ± 1.16	0.158[b]
U-PTV (mm)	18.17 ± 2.54	16.04 ± 2.57	15.69 ± 2.77	17.25 ± 2.96	< **0.001**[a]
SPA (°)	133.23 ± 4.60	131.30 ± 6.03	130.74 ± 4.82	132.25 ± 5.54	0.069[a]
Tongue					
TGL (mm)	55.77 ± 4.66	57.01 ± 5.26	56.44 ± 4.93	55.31 ± 6.10	0.469[a]
TGH (mm)	26.60 ± 2.83	26.66 ± 2.80	27.54 ± 2.67	26.13 ± 2.79	0.058[b]
Td to PP (mm)	4.55 ± 2.41	6.03 ± 2.15	5.15 ± 2.40	5.70 ± 2.68	**0.004**[b]
T-PTV (mm)	34.21 ± 3.42	36.93 ± 3.56	36.49 ± 3.56	33.45 ± 6.15	< **0.001**[b]
Upper airway					
PNS-AD1 (mm)	17.62 ± 2.93	20.33 ± 2.10	15.56 ± 2.73	20.11 ± 2.09	< **0.001**[b]
PNS-AD2 (mm)	11.61 ± 2.06	14.79 ± 1.91	10.72 ± 1.78	16.52 ± 2.09	< **0.001**[a]
UAS (mm)	8.26 ± 1.96	9.94 ± 1.99	9.20 ± 1.94	8.16 ± 2.36	< **0.001**[a]
IAS (mm)	8.03 ± 2.22	10.91 ± 2.33	10.40 ± 2.69	8.08 ± 2.16	< **0.001**[b]
V-LPW (mm)	11.15 ± 2.67	13.25 ± 2.33	12.72 ± 2.42	11.98 ± 2.03	< **0.001**[a]
VAL (mm)	46.58 ± 4.24	47.22 ± 4.79	47.92 ± 4.49	48.75 ± 4.28	0.142[a]

Note:

(1) AHO: adenoid hypertrophy only; THO: tonsillar hypertrophy only; AH + TH: adenoid and tonsillar hypertrophy group; CG: control group.

(2) Measurement data were presented as mean±standard deviation (mean±SD), while categorical data were expressed as n (%).

(3) [a] One-way ANOVA analysis; [b] Kruskal-Wallis test; [c] chi-square test. The values highlighted in bold indicate statistical significance.

The Td-PP value was higher in the THO group than in the AHO group, indicating that children with tonsillar enlargement had a lower tongue position. Moreover, the tip of the tongue in the THO and AH + TH groups was found to be further away from the PTV line than in the AHO group and healthy controls.

The sagittal airway parameters revealed that children in the AHO group and AH + TH group had lower PNS-AD1 and PNS-AD2 values than the other two groups. Children in the THO group had higher UAS values than the AHO group and healthy subjects. Moreover, the THO group and AH + TH group had significantly larger IAS values than the AHO group and healthy controls. Lastly, children in the AHO group had smaller V-LPW parameters than those in the THO group and AH + TH group.

Discussion

Lateral cephalogram serves as a valuable orthodontic diagnostic tool, providing a convenient and effective means of identifying and assessing adenotonsillar hypertrophy [21, 23]. This imaging technique offers a lateral X-ray view of the head and neck, enabling orthodontists to visualize the adenoids, tonsils, and their anatomical relationship with the pharyngeal space [10, 24, 25]. Based on the findings from our cephalometry study comparing children with adenotonsillar hypertrophy, tonsillar hypertrophy, adenoid hypertrophy, and healthy controls, we observed several distinct outcomes regarding the hyoid bone position and upper airway morphology.

Hyoid bone position

After pairwise comparison, we did not observe statistically significant differences in hyoid bone position between the hypertrophic and control groups, suggesting

Table 3 *P* values of pairwise comparisons of cephalometric variables among different groups

	AHO vs. THO	AHO vs. AH+TH	AHO vs. CG	THO vs. AH+TH	THO vs. CG	AH+TH vs. CG
Hyoid bone position						
Hy-Me (mm)	**0.005**	1.000	0.667	**0.045**	0.501	1.000
Hy-RGn (mm)	**0.003**	1.000	0.524	**0.036**	0.497	1.000
C3-RGn (mm)	**0.001**	0.419	0.600	0.094	0.282	1.000
Soft palate						
SPL (mm)	**0.014**	**0.020**	1.000	1.000	**0.008**	**0.012**
U-PTV (mm)	**0.003**	< **0.001**	0.790	1.000	0.311	**0.025**
Tongue						
Td to PP (mm)	**0.004**	1.000	0.103	0.069	1.000	1.000
T-PTV (mm)	**0.001**	**0.004**	1.000	1.000	**0.008**	**0.046**
Upper airway						
PNS-AD1 (mm)	< **0.001**	**0.003**	**0.002**	< **0.001**	1.000	**< 0.001**
PNS-AD2 (mm)	< **0.001**	0.092	< **0.001**	< **0.001**	**0.001**	< **0.001**
UAS (mm)	**0.001**	0.089	1.000	0.398	**0.001**	0.062
IAS (mm)	< **0.001**	< **0.001**	1.000	1.000	< **0.001**	< **0.001**
V-LPW (mm)	**0.001**	**0.004**	0.704	1.000	0.126	0.728

Note:

(1) AHO: adenoid hypertrophy only; THO: tonsillar hypertrophy only; AH+TH: adenoid and tonsillar hypertrophy group; CG: control group.

(2) Bonferroni method was employed for post-hoc pairwise comparisons.

(3) The values highlighted in bold indicate statistical significance.

that adenotonsillar hypertrophy may not affect the hyoid position when compared to healthy children. Whereas, significant differences were noted within the hypertrophic group, indicating that the location of hypertrophy could influence the hyoid position. Children in the THO group had significantly higher Hy-Me and Hy-RGn values than children in the AHO group, suggesting a greater distance between the hyoid bone and the mandibular mentum in individuals with tonsillar hypertrophy. We postulated that the hypertrophy of the tonsils caused airway obstruction in the oropharynx. To maintain an unobstructed airway, children may exhibit compensatory mandibular protrusion to widen the oropharyngeal passage. The higher C3-RGn values observed in children with tonsillar hypertrophy may support this conjecture. In contrast, in children with adenoid hypertrophy, compensatory open-mouth breathing due to nasopharyngeal obstruction leads to clockwise rotation of the jaw, thereby causing the mentum being closer to the hyoid bone. This could explain the difference in hyoid bone position between the two groups.

The findings from several studies investigating the impact of adenotonsillar hypertrophy on hyoid bone position remain inconclusive. Baik et al. found that the hyoid bone was lower and further away from the cervical spine in children with enlarged tonsils compared to healthy children [26]. They suggested that the downward displacement of the hyoid bone could result from airway obstruction and represents a compensatory response. However, Kawashima et al. found that tonsillar hypertrophy did not exert a significant impact on hyoid bone position in pediatric patients [27], which is similar to our findings. Mohamed et al. also found no significant impact of tonsil hypertrophy on the sagittal position of the hyoid bone; but their study showed that children with adenotonsillar hypertrophy exhibited an elevated hyoid position [6]. The variations may be attributed to differences in imaging techniques and methodologies employed for diagnosing adenotonsillar hypertrophy. Currently, there are numerous debates regarding the impact of adenotonsillar hypertrophy on hyoid bone position, highlighting the need for future high-quality normative studies to elucidate their correlation.

Upper airway morphology

Adenotonsillar hypertrophy can result in various structural and functional alterations within the upper airway, with significant implications for breathing, particularly during sleep, and may contribute to the development of OSA and other respiratory or sleep disorders [28]. In this section, we present an overview of how adenotonsillar hypertrophy affects upper airway morphology.

Our findings suggest that children in the AHO group exhibit greater elongation of the soft palate compared to those with tonsillar hypertrophy. This observation may result from reduced nasal airflow and compensatory mouth breathing in children with adenoid hypertrophy [29]. A study on fluid dynamics has demonstrated that airflow velocity during oral breathing is significantly higher than during nasal breathing, leading to a more chaotic and unstable airflow pattern [30]. We hypothesize that this accelerated and unsteady airflow may contribute to the relative elongation of the soft palate. Similarly, we discovered that the tip of the soft palate in the AHO group was further distanced from the PTV line, which partially reflects the outcome of an elongated soft palate. Additionally, the soft palate length was shorter in the THO group than in healthy controls. Hypertrophic tonsils can obstruct the oropharyngeal airway [18, 31, 32], and this obstruction may cause compensatory nasopharyngeal airflow, leading to soft palate shortening to maintain the nasopharyngeal airway. Nevertheless, previous studies have found that children with enlarged tonsils have a longer soft palate than healthy children, which contradicts our findings [27]. The variation in results may be due to heterogeneity in diagnostic methods and differences in sample sources.

It was observed that children in the THO group exhibited a lower tongue position compared to children with adenoid hypertrophy. Furthermore, the tip of the tongue in the THO group and AH+TH group was positioned further away from the PTV line. For children with enlarged tonsils who exhibit a lower tongue position, a potential explanation is that the location of the tonsils can directly cause physical obstruction in the oropharynx, causing children to involuntarily adjust their tongue position to improve respiratory passage smoothness. Lan et al. suggested that children may require tongue protrusion to alleviate airway blockage [33]. Consequently, due to the anterior extension of the tongue body, the tip of the tongue in children with enlarged tonsils is located further from the PTV line.

This study revealed numerous statistically significant variations in sagittal airway width among children with adenotonsillar hypertrophy. Firstly, the values of PNS-AD1 and PNS-AD2 were reduced in the AHO group and AH+TH group. This finding can be attributed to the significant space occupied by the adenoids in the nasopharyngeal airway, leading to a narrowing of the soft tissue airway width. These results suggest that PNS-AD1 and PNS-AD2 may serve as indicators for assessing the extent of airway obstruction caused by adenoids. Secondly, children with enlarged tonsils exhibited significantly higher UAS values compared to those in the AHO group and healthy subjects, indicating a broader pharyngeal airway space behind the soft palate in children with tonsillar hypertrophy. Solow et al. illustrated that upper airway stability is maintained through a complex interplay of morphological, positional, and physiological factors [34]. Therefore, we speculate that the upper airway may undergo functional remodeling in response to tonsil hypertrophy to maintain stable airflow. This adaptation may be reflected in morphological alterations in the airway posterior to the soft palate. Additionally, children with enlarged tonsils exhibited significantly higher IAS values compared to those with normal tonsils, indicating an increase in inferior airway space among these children. This finding aligns with previous speculation suggesting that children with tonsillar hypertrophy may exhibit compensatory mandibular protrusion to facilitate oropharyngeal passage dilation and maintain airway patency. Finally, we observed that the V-LPW values of the AHO group were the smallest among the four groups, representing a narrower airway width behind the epiglottis in children with adenoid hypertrophy. This phenomenon may be due to mouth breathing caused by adenoid hypertrophy, counterclockwise rotation of the mandible, and laryngeal airway constriction.

By conducting a comprehensive analysis of the airway using lateral cephalogram, orthodontists can identify upper airway abnormalities that may not be immediately apparent through clinical examination alone. Our study has revealed significant differences in airway morphology between children with adenotonsillar hypertrophy (ATH) and healthy controls. These findings underscore the significance of integrating airway analysis into orthodontic treatment plans, enabling the identification of potential causes of malocclusion and "airway threats" that impact children's overall well-being. Airway analysis in children seeking for orthodontic treatment can assist orthodontists in the early detection of at-risk pediatric patients, facilitating timely referral to otolaryngology for OSA risk assessment and contributing to tailored diagnostic and therapeutic approaches.

Strengths and limitations

The findings of this study are significant for understanding the relationship between adenotonsillar hypertrophy, hyoid bone position, and upper airway morphology. The observed changes in hyoid bone position and upper airway morphology suggest that adenotonsillar hypertrophy may lead to alterations in the anatomical structure of soft and hard tissues, potentially contributing to obstructive sleep apnea and sleep-related breathing disorders [35]. Notably, orthodontic treatment has been found to significantly improve upper airway morphology and hyoid bone position [36], underscoring the importance of considering these factors in orthodontic treatment. Our study supports the concept that adenotonsillar hypertrophy in children is associated with distinct alterations in hyoid bone position and upper airway morphology. These findings emphasize the importance of early identification and management of adenotonsillar hypertrophy to prevent or alleviate obstructive sleep apnea and its consequences.

The limitations of our study must be acknowledged. The cross-sectional design of the study limits the ability to establish causal relationships. Longitudinal studies are needed to determine whether the observed morphological changes directly result from adenotonsillar hypertrophy or if they precede its development. Furthermore, the diagnosis of adenoid and tonsil hypertrophy in our study primarily relied on lateral cephalogram. It is important to note that the findings may not be applicable if alternative criteria are employed for diagnosing adenotonsillar hypertrophy. Previous studies have reported the impact of different skeletal patterns on hyoid bone position [37, 38], highlighting the need to appropriately expand the sample size for further subgroup analysis. Future research should encompass longitudinal designs and larger sample sizes, investigating the reversibility of the observed changes following adenotonsillectomy and exploring potential correlations between these anatomical changes and improvements in clinical symptoms. Moreover, further investigation is warranted regarding the effects of orthodontic or orthopedic interventions on hyoid bone position and upper airway morphology.

Conclusions

Given the limitations of this study and the available data, we have identified that children aged 6–8 years seeking for orthodontic treatment are likely to exhibit the following hyoid bone position and upper airway morphological characteristics:

(1) The relative position of the hyoid bone to the mentum increases in children with tonsillar hypertrophy compared to those with adenoid hypertrophy. However, the presence of enlarged adenoids or tonsils does not seem to induce alterations in the position of the hyoid bone when compared to healthy children.
(2) The length of the soft palate in children with enlarged adenoids is greater than in children with enlarged tonsils.
(3) Children with enlarged tonsils exhibit a lower tongue position and forward tongue protrusion.
(4) Children with tonsillar hypertrophy and adenotonsillar hypertrophy show a wider lower airway space. In contrast, children with adenoid hypertrophy have a narrower airway width behind the epiglottis.

The limitations in study methods and sample sources should be considered when interpreting these findings, as they may not be universally applicable to all children. Further research is needed to validate the generalizability of the results presented in this study within the broader pediatric population.

Abbreviations

ATH	Adenotonsillar hypertrophy
OSA	Obstructive sleep apnea
AHO	Adenoid hypertrophy only
THO	Tonsillar hypertrophy only
AH+TH	Adenoid and tonsillar hypertrophy
CG	Control group
SPL	Length of the soft palate
ICC	Intraclass correlation coefficient

Acknowledgements
Not applicable.

Authors' contributions
Y.L. contributed to design of the work, data acquisition, analysis, interpretation of data and draft the work. S.Y. contributed to interpretation of data and draft the work. J.Z. contributed to data acquisition. F.H. contributed to interpretation of data and critically revise the manuscript. T.Z. contributed to design of the work, interpretation of data and critically revise the manuscript. H.H. contributed to the conception, design of the work, interpretation of data and critically revise the manuscript.

Funding
This work was supported by the Wuhan Knowledge Innovation Project (No. 2022020801020502), Wuhan University School and Hospital of Stomatology Clinical Research Project (No. LYZX202101), Sanming Project of Medicine in Shenzhen Nanshan (No. SZSM202103005).

Data availability
The data supporting the findings of this study can be obtained upon reasonable request from the corresponding author.

Declarations

Ethics approval and consent to participate
This retrospective study, which utilized routinely collected healthcare data, was granted approval by the Ethics Committee of School & Hospital of Stomatology, Wuhan University (Approval number: WDKQ2024-B45) to be conducted without obtaining informed consent from patients.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]State Key Laboratory of Oral and Maxillofacial Reconstruction and Regeneration, Key Laboratory of Oral Biomedicine Ministry of Education, Hubei Key Laboratory of Stomatology, School and Hospital of Stomatology, Wuhan University, Wuhan, China
[2]Department of Orthodontics, School and Hospital of Stomatology, Wuhan University, Luoyu Rd. 237, Wuhan 430079, China
[3]Department of Oral Radiology, School and Hospital of Stomatology, Wuhan University, Wuhan, China
[4]Center for Dentofacial Development and Sleep Medicine, School and Hospital of Stomatology, Wuhan University, Wuhan, China
[5]Center for Orthodontics and Pediatric Dentistry at Optics Valley Branch, School and Hospital of Stomatology, Wuhan University, Wuhan, China
[6]Division of Dentistry, School of Medical Sciences, Faculty of Biology, Medicine and Health, The University of Manchester, Manchester, UK
[7]Hubei Provincial Clinical Research Center for Dentofacial Deformities in Children, School and Hospital of Stomatology, Wuhan University, Wuhan, China

Received: 6 June 2024 / Accepted: 30 October 2024
Published online: 10 November 2024

References

1. Samara P, Athanasopoulos M, Athanasopoulos I. Unveiling the enigmatic adenoids and tonsils: exploring immunology, physiology, microbiome dynamics, and the transformative power of surgery. Microorganisms. 2023;11(7):1624.
2. Papaioannou G, Kambas I, Tsaoussoglou M, Panaghiotopoulou-Gartagani P, Chrousos G, Kaditis AG. Age-dependent changes in the size of adenotonsillar tissue in childhood: implications for sleep-disordered breathing. J Pediatr. 2013;162(2):269–74.
3. Howie AJ. Scanning and transmission electron microscopy on the epithelium of human palatine tonsils. J Pathol. 1980;130(2):91–8.
4. Evcimik MF, Dogru M, Cirik AA, Nepesov MI. Adenoid hypertrophy in children with allergic disease and influential factors. Int J Pediatr Otorhinolaryngol. 2015;79(5):694–7.
5. Marcus CL, Brooks LJ, Draper KA, Gozal D, Halbower AC, Jones J, et al. Diagnosis and management of childhood obstructive sleep apnea syndrome. Pediatrics. 2012;130(3):e714–55.
6. Mohamed AS, Habumugisha J, Cheng B, Zhao M, Bu W, Liu L, et al. A cone-beam computed tomography study of hyoid bone position and airway volume in subjects with obstructive and nonobstructive adenotonsillar hypertrophy. Angle Orthod. 2023;93(4):467–75.
7. von Arx T, Lozanoff S, Bornstein MM. Extraoral anatomy in CBCT – a literature review. Part 4: pharyngocervical region. Swiss Dent J. 2020;130(10):768–84.
8. Samaha CJ, Tannous HJ, Salman D, Ghafari JG, Amatoury J. Role of surgical hyoid bone repositioning in modifying upper airway collapsibility. Front Physiol. 2022;13:1089606.
9. Amatoury J, Kairaitis K, Wheatley JR, Bilston LE, Amis TC. Peripharyngeal tissue deformation and stress distributions in response to caudal tracheal displacement: pivotal influence of the hyoid bone? J Appl Physiol. 2014;116(7):746–56.
10. Duan H, Xia L, He W, Lin Y, Lu Z, Lan Q. Accuracy of lateral cephalogram for diagnosis of adenoid hypertrophy and posterior upper airway obstruction: a meta-analysis. Int J Pediatr Otorhinolaryngol. 2019;119:1–9.
11. World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA. 2013;310(20):2191–4.
12. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The strengthening the reporting of Observational studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Lancet. 2007;370(9596):1453–7.
13. Alfuriji S, Chen Y, Ahmed IH, Yen EH, Pliska BT, Almeida FR. Craniofacial features of adult obese obstructive sleep apnoea patients in relation to the obesity onset - A pilot study. Orthod Craniofac Res. 2024;27(3):364–75.
14. Kim JE, Yim S, Choi JY, Kim S, Kim SJ, Baek SH. Effects of the long-term use of maxillary protraction facemasks with skeletal anchorage on pharyngeal airway dimensions in growing patients with cleft lip and palate. Korean J Orthod. 2020;50(4):238–48.
15. Zhou X, Xiong X, Yan Z, Xiao C, Zheng Y, Wang J. Hyoid bone position in patients with and without temporomandibular joint osteoarthrosis: a cone-beam computed tomography and cephalometric analysis. Pain Res Manag. 2021;2021:4852683.
16. Liu Y, Park YC, Lowe AA, Fleetham JA. Supine cephalometric analyses of an adjustable oral appliance used in the treatment of obstructive sleep apnea. Sleep Breath. 2000;4(2):59–66.
17. Fujioka M, Young LW, Girdany BR. Radiographic evaluation of adenoidal size in children: adenoidal-nasopharyngeal ratio. Am J Roentgenol. 1979;133(3):401–4.
18. Baroni M, Ballanti F, Franchi L, Cozza P. Craniofacial features of subjects with adenoid, tonsillar, or adenotonsillar hypertrophy. Prog Orthod. 2011;12(1):38–44.
19. Zhao T, Yang Z, Ngan P, Luo P, Zhang J, Hua F, et al. Association between adenotonsillar hypertrophy and dentofacial characteristics of children seeking for orthodontic treatment: a cross-sectional study. J Stomatol Oral Maxillofac Surg. 2023;125(4):101751.
20. Wormald PJ, Prescott CA. Adenoids: comparison of radiological assessment methods with clinical and endoscopic findings. J Laryngol Otol. 1992;106(4):342–4.
21. Lv C, Yang L, Ngan P, Xiao W, Zhao T, Tang B, et al. Role of the tonsil-oropharynx ratio on lateral cephalograms in assessing tonsillar hypertrophy in children seeking orthodontic treatment. BMC Oral Health. 2023;23(1):836.
22. Springate SD. The effect of sample size and bias on the reliability of estimates of error: a comparative study of Dahlberg's formula. Eur J Orthod. 2012;34(2):158–63.
23. Zhao T, Zhou J, Yan J, Cao L, Cao Y, Hua F, et al. Automated adenoid hypertrophy assessment with lateral cephalometry in children based on artificial intelligence. Diagnostics. 2021;11(8):1386.
24. Shen Y, Li X, Liang X, Xu H, Li C, Yu Y, et al. A deep-learning-based approach for adenoid hypertrophy diagnosis. Med Phys. 2020;47(5):2171–81.
25. Liu JL, Li SH, Cai YM, Lan DP, Lu YF, Liao W, et al. Automated radiographic evaluation of adenoid hypertrophy based on VGG-Lite. J Dent Res. 2021;100(12):1337–43.
26. Baik UB, Suzuki M, Ikeda K, Sugawara J, Mitani H. Relationship between cephalometric characteristics and obstructive sites in obstructive sleep apnea syndrome. Angle Orthod. 2002;72(2):124–34.
27. Kawashima S, Peltomäki T, Sakata H, Mori K, Happonen RP, Rönning O. Craniofacial morphology in preschool children with sleep-related breathing disorder and hypertrophy of tonsils. Acta Paediatr. 2002;91(1):71–7.
28. Tran-Minh D, Phi-Thi-Quynh A, Nguyen-Dinh P, Duong-Quy S. Efficacy of obstructive sleep apnea treatment by antileukotriene receptor and surgery therapy in children with adenotonsillar hypertrophy: a descriptive and cohort study. Front Neurol. 2022;13:1008310.
29. Sun Q, Dong J, Zhang Y, Tian L, Tu J. Numerical modelling of micron particle inhalation in a realistic nasal airway with pediatric adenoid hypertrophy: a virtual comparison between pre- and postoperative models. Front Pediatr. 2023;11:1083699.
30. Suzuki M, Tanuma T. The effect of nasal and oral breathing on airway collapsibility in patients with obstructive sleep apnea: computational fluid dynamics analyses. PLoS ONE. 2020;15(4):e0231262.
31. Franco LP, Souki BQ, Cheib PL, Abrão M, Pereira TB, Becker HM, et al. Are distinct etiologies of upper airway obstruction in mouth-breathing children associated with different cephalometric patterns? Int J Pediatr Otorhinolaryngol. 2015;79(2):223–8.
32. Niemi P, Markkanen S, Helminen M, Rautiainen M, Katila MK, Saarenpää-Heikkilä O, et al. Association between snoring and deciduous dental development and soft tissue profile in 3-year-old children. Am J Orthod Dentofac Orthop. 2019;156(6):840–5.
33. Lan Y, Chen J, Chen S, He Y, Huang F. Influences of adenoid hypertrophy on children's maxillofacial development. Healthcare. 2023;11(21):2812.
34. Solow B, Skov S, Ovesen J, Norup PW, Wildschiødtz G. Airway dimensions and head posture in obstructive sleep apnoea. Eur J Orthod. 1996;18(6):571–9.
35. Shintani T, Asakura K, Kataura A. Evaluation of the role of adenotonsillar hypertrophy and facial morphology in children with obstructive sleep apnea. J Otorhinolaryngol Relat Spec. 1997;59(5):286–91.
36. Tanaka M, Seto Y, Kobayashi SJAOJ. Changes in pharyngeal airway space and hyoid bone position after Bionator treatment of skeletal class II malocclusions. Australas Orthod J. 2023;39:71–81.
37. Cheng JH, Hsiao SY, Chen CM, Hsu KJ. Relationship between hyoid bone and pharyngeal airway in different skeletal patterns. J Dent Sci. 2020;15(3):286–93.
38. Mohamed AS, Habumugisha J, Cheng B, Zhao M, Guo Y, Zou R, et al. Three-dimensional evaluation of hyoid bone position in nasal and mouth breathing subjects with skeletal class I, and Class II. BMC Oral Health. 2022;22(1):228.

Publisher's note