BMC Oral Health

RESEARCH

Open Access

Upper airway and hyoid bone-related morphological parameters associated with the apnea-hypopnea index and lowest nocturnal oxygen saturation: a cephalometric analysis

Zhili Dong[1†], Yue Zeng[2†], Jieyi Chen[1], Liping Wu[1*] and Hong Hong[1*]

Abstract

Background Obstructive sleep apnea (OSA) is a common disorder characterized by repetitive complete or partial closure of the upper airway during sleep, resulting in sleep fragmentation and oxygen desaturation. Cephalogram is recognized as an effective diagnostic tool for predicting OSA risk in clinical practice. This study aims to assess and analyze the morphological characteristics of the upper airway and hyoid bone position associated with OSA using data from polysomnography studies and two-dimensional cephalometric analysis.

Methods The study included lateral cephalograms and polysomnography reports from the records of 105 adult (64 males & 41 females) patients who underwent comprehensive clinical examination. The severity of OSA was evaluated based on the apnea-hypopnea index (AHI) and lowest nocturnal oxygen saturation ($LSaO_2$). The participants were divided into male and female groups to investigate the correlation between cephalometric parameters and OSA severity. Thirteen cephalometric parameters, including eleven linear measurements and two angular measurements, were analyzed. The significance level was set at P-value < 0.05.

Results The male group exhibited significantly higher severity of OSA compared to the female group, as indicated by higher AHI and lower $LSaO_2$. There was an inverse association between AHI values with width of upper airway as well as distance between hyoid bone position relative to mandibular plane in both male and female groups. Additionally, only the male group showed a correlation between hyoid bone position relative to gonion/third-fourth vertebrae positions with AHI values. 4 out of 7 parameters associated with AHI in male group remained correlated with $LSaO_2$, while in females only the distance between hyoid bone and line formed by ptergoid and pterygomaxillary fissure point showed correlation with $LSaO_2$.

[†]Zhili Dong and Yue Zeng contributed equally to this work.

*Correspondence:
Liping Wu
wulping@mail.sysu.edu.cn
Hong Hong
hongh7@mail.sysu.edu.cn

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

Conclusion Correlation analysis revealed that a narrower upper airway was positively associated with increased AHI, while an inferiorly positioned hyoid bone in relation to mandible was negatively correlated with $LSaO_2$. Our findings highlight the importance of several cephalometric parameters in predicting OSA severity based on AHI and $LSaO_2$ levels; moreover, certain parameters exhibited significant gender-specific associations.

Keywords Obstructive sleep apnea, Lateral cephalogram, Apnea-hypopnea index, Lowest nocturnal oxygen saturation, Upper airway and hyoid bone morphology

Background

Obstructive sleep apnea (OSA) is a prevalent disorder characterized by recurrent episodes of airway obstruction during sleep, resulting in symptoms such as snoring, witnessed apnea, and excessive daytime sleepiness [1]. Recent studies have demonstrated a rising prevalence of both pediatric and adult-onset OSA, primarily attributed to the increasing rates of obesity and heightened air pollution. Additionally, hypertension, male sex, age, adenotonsillar hypertrophy, smoking, and diet including supplementations (e.g. vit. D and calcium level) are also correlated with the prevalence and severity of OSA [2–4]. Children with specific congenital conditions such as cleft deformities or Down syndrome may also encounter an elevated susceptibility to OSA due to obstructive factors affecting multiple levels of the airway [5, 6].

As a global health issue, pediatric OSA has been associated with neurocognitive deficits, learning difficulties, behavioral issues, stunted growth, and impaired cardiac function [7, 8]. Recent estimates suggest that OSA affects more than 900 million adults aged 30–69 globally, with approximately half experiencing moderate to severe forms of the condition [9]. It is particularly concerning in the elderly population due to its association with various systemic diseases including hypertension, diabetes mellitus, stroke, atherosclerosis, and an elevated risk of cardiovascular mortality [10]. Therefore, early screening and diagnosis of OSA are essential for reducing its negative impact on general health. While polysomnography (PSG) has been widely applied as a screening tool for OSA diagnosis based on various physiologic parameters such as oxygen saturation, brain electroencephalographic activity, eye movements, heart rate, and respiratory function [11, 12], it lacks detailed morphological evaluation of the upper airway structure, making it difficult to identify the obstruction site and predict the treatment outcomes [13]. Anatomical parameters of the craniofacial region including airway width, hyoid bone position, tongue position and volume, an increased mandibular plane angle, as well as maxillary and mandibular retrognathia, have been demonstrated to be determinative factors in the pathogenesis of certain OSA cases, hence complementary diagnostic tools are in need for a comprehensive evaluation of these factors [14–16].

Cephalometry is recognized as an efficient screening procedure to evaluate skeletal and soft tissue characteristics due to its cost-effectiveness, low radiation exposure, and ease of implementation [17, 18]. The current diagnostic and severity grading criteria for OSA are based on the apnea hypopnea index (AHI), which represents the number of apnea and/or hypopnea events per hour during sleep, regardless of related nocturnal oxygen desaturation [19]. Consequently, most cephalometric studies have investigated the correlation between craniofacial morphological characteristics and severity of OSA solely based on AHI values [15]. However, substantial evidence has shown that AHI alone does not fully reflect the clinical symptoms and prognosis of OSA patients. Mediano et al. reported that individuals with similar AHIs may exhibit varying levels of daytime sleepiness, sleep latency, and nocturnal oxygenation [20]. Asano et al. found that although some patients share a similar mean AHI, the severity of hypoxia and incidence of cardiovascular events were significantly different [21]. Wang et al. suggested that oxygen saturation below 90% during total sleep time was independently associated with the risk of hypertension in severe OSA patients after adjusting for traditional risk factors such as AHI and body mass index [22]. Considering these aforementioned studies, it is crucial to assess the correlation between cephalometric parameters and oxygen saturation in OSA patients to identify potential risk factors for nocturnal hypoxia and assist the treatment planning for this condition. Therefore, the aim of this study is to identify upper airway dimensions and hyoid bone position related variables associated with OSA severity using lateral cephalograms, considering both AHI values and lowest oxygen saturation as indicators.

Methods

Study design and samples

The study was designed as a retrospective cohort study. The study population included patients referred to the Department of Orthodontics in Hospital of Stomatology, Sun Yat-sen University, between January 2019 and June 2024. This study was approved by the Medical Ethics Committee of Hospital of Stomatology, Sun Yat-sen University (Approval No.KQEC-2024-99-01). Inclusion criteria were as follows: age over 18 years, diagnosis of OSA confirmed by PSG, availability of a digital lateral cephalogram taken with the same cephalostat positioning in an upright position, natural head posture, and centric

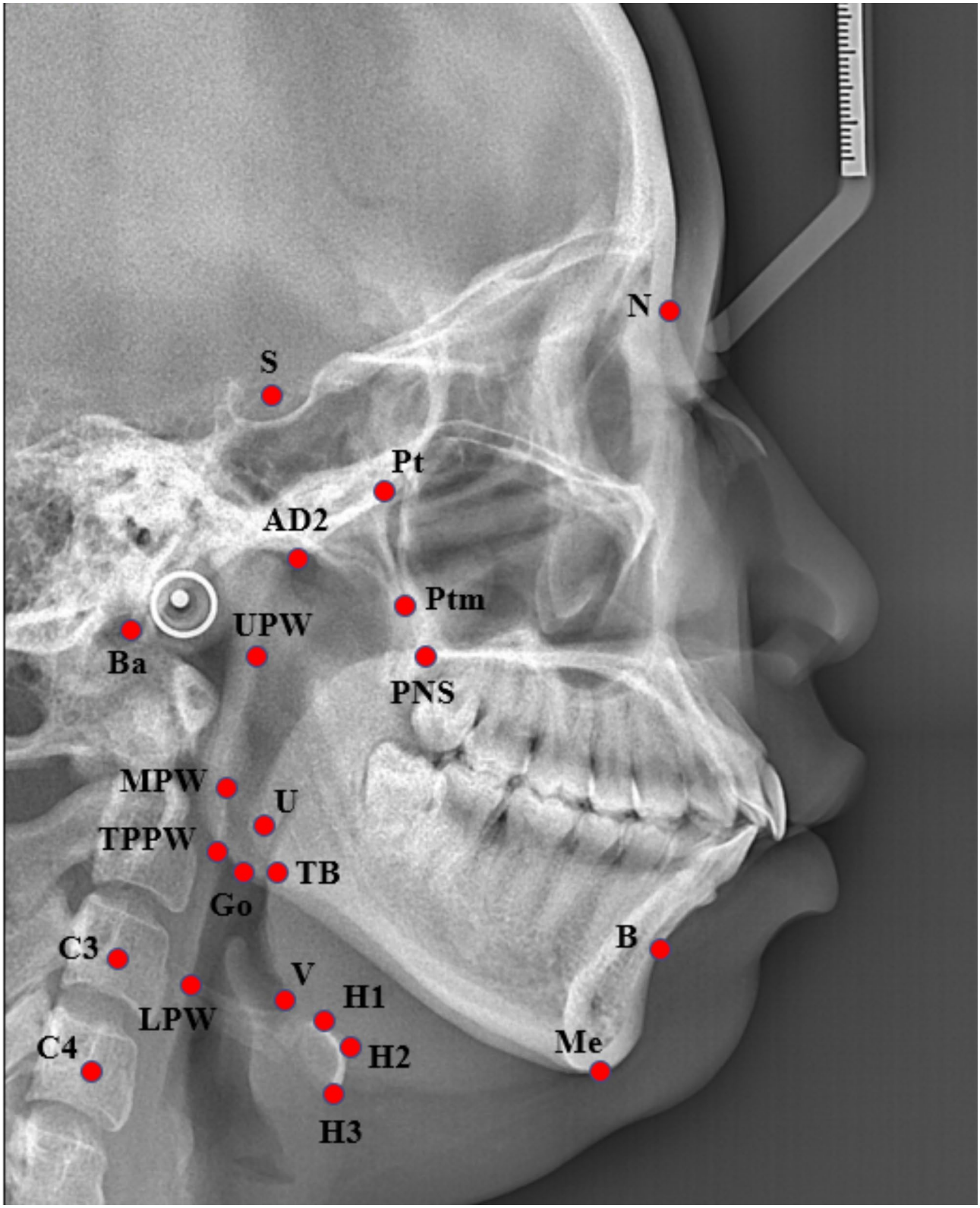

Fig. 1 (See legend on next page.)

(See figure on previous page.)

Fig. 1 Graphical representation of landmarks: B, supramentale; N, Nasion; Me, Menton, most inferior point on bony chin; S, sella, centre of sella turcica; Ba, basion; Go, gonion; PNS, posterior nasal spine; Pt, Ptergoid; Ptm, pterygomaxillary fissure point; U, the tip of the uvula; MPW, foot point of perpendicular line from point U to posterior pharyngeal wall; TPPW, point of intersection of posterior pharyngeal wall and extension of line B-Go; TB, point of intersection of base of tongue and extension of line B-Go; V, the most posteroinferior point on base of tongue; LPW, foot point of perpendicular line from point V to posterior pharyngeal wall; C3, the middle point of the third vertebra; C4, the middle point of the forth vertebra; AD2, the intersection point between the perpendicular line connecting PNS and Ba-S and the posterior pharyngeal wall; H1, the most superior point of hyoid bone; H2, the most anterior point of hyoid bone; H3, the most inferior point of hyoid bone

occlusion at the end-tidal breathing phase [23]. Patients with craniofacial or growth abnormalities, history of orthodontic treatment, tonsillectomy or adenoidectomy were excluded. Based on these inclusion/exclusion criteria, a total of 105 patients were included in this observational retrospective study. All data used in this study were obtained from medical record review.

PSG

All participants involved in this study underwent standard overnight polysomnographic monitoring. Respiratory events were diagnosed as apnea or hypopnea, and the apnea-hypopnea index (AHI) was calculated as the total number of events per hour of sleep and classified according to the American Academy of Sleep Medicine Criteria 2012 (version 2.0) [24]. AHI and lowest oxygen saturation ($LSaO_2$) level during sleep were recorded for further analysis in this study.

Cephalometric analysis

The standardized lateral cephalogram were obtained using the same cephalostat at the Hospital of Stomatology, Sun Yat-sen University. The patients were positioned upright with their head in a natural posture and centric occlusion, at the end of tidal breathing. Cephalometric tracings were performed by an examiner who was blinded to the PSG reports and clinical examination results. All angular and linear measurements were calculated using the Digident software (Boltzmann Zhibei Technology Co., Ltd, Chengdu, China) [25]. Thirteen variables of linear and angular measurements were derived from fourteen landmarks digitized on each radiograph, as described in Fig. 1; Table 1.

Statistical analysis

The statistical analysis was performed using SPSS 25.0 software (SPSS Inc., Chicago, IL, USA). Descriptive data were presented as mean ± standard deviation (SD), median with interquartile range (IQR), or number (percentage), as appropriate. Correlation coefficients were measured through Pearson correlation analysis if the variables followed a normal distribution, while those that were not normally distributed were examined through Spearman rank correlation analysis. Based on the univariate analyses, the correlation between the cephalometric variables and severity of OSA was determined by multiple regression analysis. $P<0.05$ was considered statistically significant.

The sample size calculation was performed based on a previous study [26]. In order to detect a correlation of ± 0.45 using a two-sided hypothesis test with a significance level of 0.05 and a power of 0.80, 36 subjects would be required for each group.

Results

Demographic data

A total of 105 adult participants were included in this study, with a male to female ratio of 64:41. The mean age was 28.5 ± 7.28 years, ranging from 18 to 52 years. The mean age for males was 28.8 ± 7.49 years, while for females it was 28.0 ± 7.01 years (Table 2 provides detailed demographic data). Correlation analysis showed that AHI was negatively correlated with $LSaO_2$ in both gender groups (Male: r=-0.644, $P<0.001$, Female: r=-0.561, $P<0.001$). To investigate gender differences in the PSG results and craniofacial parameters used in this study, the participants were divided into male and female groups accordingly. As both AHI and $LSaO_2$ showed significant variation between different genders, further analysis was conducted separately for each gender group to explore potential gender-specific predictors for OSA risk.

Correlation analysis between upper airway and hyoid bone-related parameters and OSA-severity indicators

In this study, we investigated the associations between upper airway and hyoid bone-related parameters and OSA-severity indicators (AHI and $LSaO_2$). In male individuals, U-MPW, TB-TPPW, H2-S-N, H1-VC3C4, H3-MP, H3-Go, H3-Me-Go exhibited statistically significant correlations with AHI. While U-MPW, TB-TPPW, H3-MP and H3-Me-Go demonstrated statistically significant correlations with AHI in female groups (Table 3). Regarding $LSaO_2$ levels, U-MPW, H1-VC3C4, H3-MP and H3-Go were identified as parameters with statistically significant correlations in male group. In female group, the only statistically significant parameter was H3-PtPtm (Table 4).

Multiple regression analysis between upper airway and hyoid bone-related parameters and OSA-severity indicators

Based on the results of the correlation analysis presented above, we selected the parameters that showed strong

Table 1 Description of the cephalometric measurements

Measurements	Description
Angular measurements (°)	
H2-S-N	Angle between point H2 and N at S
H3-Me-Go	Angle between point H3 and Go at Me
Linear measurements(mm)	
PNS-UPW	Distance between PNS and UPW
PNS-AD2	Distance between PNS and AD2
U-MPW	Distance between U and MPW
TB-TPPW	Distance between TB and TPPW
V-LPW	Distance between V and LPW
H3-PtPtm	Distance between H3 and line Pt-Ptm
H3-C4	Distance between H3 and C4
H1-VC3C4	Distance between H1 and perpendicular bisector of line C3-C4
H3-MP	Distance between H3 and mandibular plane
H3-Me	Distance between H3 and Me
H3-Go	Distance between H3 and Go

Note: If H3 is in front of line Pt-Ptm, the value of H3-PtPtm is greater than 0. Otherwise, H3-PtPtm is less than 0; If H1 is above the perpendicular bisector of line C3-C4, the value of H1-VC3C4 is greater than 0. Otherwise, H1-VC3C4 is less than 0

correlation with AHI and $LSaO_2$ in both gender groups to perform a multiple regression analysis.

The Multiple regression coefficients were employed to determine the correlation between the selected variables with AHI (Tables 5 and 6). The model was designed to predict AHI based on the upper airway and hyoid bone-related parameters. AHI and $LSaO_2$ were used as dependent variables to study the correlation between other independent variables. The variance inflation factor (VIF) values between 1 and 5 of the variables indicated moderate multicollinearity between the variables and AHI/$LSaO_2$. Additionally, we found a significant correlation between H1-VC3C4 with AHI in the male group. In terms of $LSaO_2$, H1-VC3C4 demonstrated a significant correlation in males, while H3-Me-Go showed a significant correlation with $LSaO_2$ in females. Both regression models proved effective in predicting the AHI and $LSaO_2$

Table 3 Correlation analysis between cephalometric parameters and AHI in male and female individuals

	Male		Female	
	Coefficient	***P* value**	**Coefficient**	***P* value**
PNS-UPW	-0.016	0.9	-0.037	0.819
PNS-AD2	-0.009	0.945	-0.136	0.369
U-MPW	-0.281	0.024*	-0.366	0.019*
TB-TPPW	-0.278	0.026*	-0.323	0.039*
V-LPW	-0.16	0.207	-0.126	0.433
H3-PtPtm	-0.141	0.265	-0.293	0.063
H2-S-N	0.259	0.039*	0.212	0.183
H3-C4	-0.049	0.698	-0.103	0.521
H1-VC3C4	-0.362	0.003**	0.17	0.288
H3-MP	0.371	0.003**	0.38	0.014*
H3-Me	-0.044	0.731	0.046	0.774
H3-Go	0.25	0.047*	0.155	0.334
H3-Me-Go	0.386	0.002**	0.361	0.02*

Note: * indicates $p<0.05$, ** indicates $p<0.01$

Table 2 Demographic, polysomnographic and cephalometric parameters

	Male	Female	Total	*P*-value (Male vs. Female)
Number	64	41	105	-
Age	28.8 ± 7.49	28.0 ± 7.01	28.5 ± 7.28	0.583
Polysomnography parameters				
AHI	12.0 (7.53, 18.9)	7.50 (5.20, 12.0)	10.5 (6.15, 18.1)	0.0017**
$LSaO_2$ (%)	86.0 (80.3, 90.0)	89.0 (85.5, 92.5)	87.0 (82.0, 90.5)	<0.001***
Cephalometric parameters				
H2-S-N	95.3 ± 4.96	96.2 ± 5.02	95.7 ± 4.98	0.391
H3-Me-Go	34.0 (25.4, 47.9)	25.3 (19.1, 35.1)	32.0 (23.5, 44.5)	<0.001***
PNS-UPW	23.0 ± 3.60	24.0 ± 3.45	23.4 ± 3.56	0.171
PNS-AD2	21.5 (19.5, 23.7)	22.4 ± 3.58	21.7 ± 3.56	0.198
U-MPW	7.41 (6.28, 8.93)	8.52 ± 2.24	8.08 ± 2.21	0.058
TB-TPPW	9.96 ± 2.19	10.4 ± 2.08	10.1 ± 2.15	0.306
V-LPW	12.1 ± 1.97	11.5 ± 1.87	11.6 (10.5, 13.3)	0.108
H3-PtPtm	-20.8 ± 8.87	-22.9 ± 7.50	-21.7 ± 8.39	0.218
H3-C4	51.7 (48.8, 55.4)	46.8 ± 4.30	49.6 ± 5.08	<0.001***
H1-VC3C4	-0.794 ± 5.91	4.02 ± 6.34	1.09 ± 7.56	<0.001***
H3-MP	20.5 ± 5.91	13.8 (11.4, 18.7)	17.3 (13.5, 22.6)	<0.001***
H3-Me	35.5 ± 6.96	34.0 ± 5.81	34.9 ± 6.55	0.386
H3-Go	42.8 ± 7.46	36.1 (31.6, 41.1)	39.8 (34.7, 45.1)	<0.001***

Note: If the sample complies with normal distribution, it is presented with average number (X) ± standard deviation (S). If the sample doesn't comply with normal distribution, it is presented with median number X (median interquartile range, IQR)

Table 4 Correlation analysis between cephalometric parameters and $LSaO_2$ in male and female individuals

	Male		Female	
	Coefficient	***P* value**	**Coefficient**	***P* value**
PNS-UPW	0.055	0.667	-0.05	0.756
PNS-AD2	0.024	0.85	0.081	0.613
U-MPW	0.282	0.024*	0.266	0.093
TB-TPPW	0.225	0.074	0.216	0.176
V-LPW	0.047	0.709	0.261	0.099
H3-PtPtm	0.053	0.676	0.44	0.004**
H2-S-N	-0.126	0.321	-0.138	0.389
H3-C4	-0.106	0.405	0.3	0.057
H1-VC3C4	0.252	0.045*	-0.3	0.056
H3-MP	-0.288	0.021*	-0.251	0.113
H3-Me	-0.06	0.639	0.087	0.586
H3-Go	-0.257	0.041*	-0.026	0.873
H3-Me-Go	-0.232	0.065	0.272	0.086

Note: * indicates $p<0.05$, ** indicates $p<0.01$, *** indicates $p<0.001$

based on the R^2 value and F value, but the level of correlation is relatively low.

Discussion

The pathogenesis of obstructive sleep apnea involves recurrent upper airway obstruction, resulting in sleep fragmentation and intermittent hypoxia during sleep. This condition affects 3-20% of the general population, with its prevalence on the rise [27]. Untreated OSA is associated with long-term detrimental health outcomes, including cognitive impairment, cardiovascular disease, and metabolic disorders, thereby imposing a significant socioeconomic burden [28].

Clinically, PSG is commonly used to assess the severity of OSA. The primary diagnostic strategies typically involve the AHI measurements derived from PSG recordings. However, AHI alone merely quantifies the frequency of apneas and hypopneas per hour of sleep, without reflecting the extent of hypoxia experienced during these events [29]. Recent studies showed that patients with the similar AHI values may exhibit variations in clinical symptoms and complications due to different level of hypoxia [30]. Fernandes et al. reported that AHI was weakly correlated with an inflammatory profile in OSA patients; while individuals experienced lower nocturnal

Table 5 Multiple regression for cephalometric variables associated with AHI in male and female individuals

Gender	Variables	B	T	*P*	VIF	R^2	F
	H3-Me-Go	0.032	0.158	0.875	3.902	0.273	F = 3.000***
	H3-Go	-0.287	-0.607	0.546	4.493		
	H3-MP	0.715	1.771	0.082	2.05		
Male	H2-S-N	0.517	1.211	0.231	1.617		
	TB-TPPW	-1.852	-1.402	0.166	3.003		
	H1-VC3C4	-0.679	-2.629	0.011*	1.436		
	U-MPW	0.48	0.332	0.741	3.512		
	H3-Me-Go	-0.071	-0.169	0.866	5.171		
	H3-MP	1.672	2.004	0.053	4.754		
Female	H3-PtPtm	-0.409	-1.107	0.276	1.265	0.329	F = 3.437**
	TB-TPPW	-0.775	-0.299	0.767	4.796		
	U-MPW	1.488	0.551	0.585	6.019		

Note: * indicates $p<0.05$, ** indicates $p<0.01$, *** indicates $p<0.001$

Table 6 Multiple regression for cephalometric variables associated with $LSaO_2$ in male and female individuals

Gender	Variables	B	T	*P*	VIF	R^2	F
	H3-Me-Go	0.095	0.892	0.376	3.276	0.219	F = 2.663**
	H3-Go	-0.023	-0.095	0.925	3.816		
	H3-MP	-0.319	-1.554	0.128	1.681		
Male	H1-VC3C4	0.37	2.613	0.011*	1.347		
	TB-TPPW	0.555	0.758	0.452	2.883		
	U-MPW	0.363	0.463	0.645	3.211		
	H3-Me-Go	-0.209	-2.136	0.040**	2.032		
	H3-PtPtm	0.151	1.043	0.305	1.412		
Female	H3-C4	0.032	0.127	0.900	1.429	0.379	F = 3.457***
	H1-VC3C4	-0.331	-1.999	0.054	1.319		
	U-MPW	0.105	0.183	0.856	1.972		
	V-LPW	0.596	1.013	0.318	1.447		

Note: * indicates $p<0.05$, ** indicates $p<0.01$, *** indicates $p<0.001$

oxygen saturation were more likely to exhibit elevated levels of total leukocytes, neutrophils, neutrophil-lymphocyte ratio, and C-reactive protein concentration, suggesting a potential correlation between nocturnal oxygen saturation and inflammation levels [31]. In addition, certain patients fail to demonstrate sufficient improvement in hypoxemia in spite of reductions observed in their AHI following treatment interventions. Therefore, pretreatment $LSaO_2$ should be considered when planning therapeutic strategies for OSA management as it closely relates to improvements achieved in oxygenation levels subsequent to OSA treatment [32].

As an effective tool to identify the risk of OSA, cephalometric analysis has been widely utilized to investigate the occurrence of OSA based on AHI [33, 34]. Nevertheless, it remains unclear whether the anatomic features of the upper airway and hyoid bone position depicted by lateral cephalograms can accurately reflect the severity of nocturnal hypoxia. Recent research implied that OSA and sleep-related hypoxia have been associated with higher rates of hospitalization and mortality among patients with Coronavirus disease 2019 (COVID-19) [35]. An analysis involving 204 orthodontic patients who tested positive for COVID-19 revealed that lower face height, vertical airway length, and a superiorly positioned hyoid bone were correlated with more severe COVID-19 symptoms, indicating that craniofacial morphological features may be a link between OSA severity and OSA-related respiratory diseases [36].

In this study, we explored the relationship between morphological characteristics observed on cephalogram and the severity of OSA based on both AHI and $LSaO_2$. As anticipated, several cephalometric parameters exhibited statistically significant correlations with AHI and $LSaO_2$, with variations observed between male and female groups. U-MPW and TB-TPPW reflected the width of upper airway, which are significantly correlated with AHI in both gender groups. H3-MP and H3-Me-Go represented the position of hyoid bone. Our findings showed that a lower positioned hyoid bone with a greater distance from the hyoid bone to the inferior line of the mandible were associated with higher AHI values in male and female groups. Similarly, Mathilde Jadoul et al. found that the distance between the hyoid bone and the mandibular plane was increased in OSA patients compared to the non-OSA group, which may be partially attributed to a reduced size of mandible [37]. Additionally, H2-S-N, H1-VC3C4, and H3-Go showed statistical significance only in males. A greater H2-S-N value indicated a more anteriorly positioned hyoid bone linked to higher AHI levels, while larger values of H1-VC3C4 and H3-Go reflected an elongated distance from the hyoid bone to mandible. The results on H3-Go align well with previous studies [14, 38]. In brief, our findings suggest that U-MPW, TB-TPPW, H3-MP, and H3-Me-Go can serve as common indicators for higher AHI levels across both genders; however, H2-S-N, H1-VC3C4, and H3-Go may be more suitable for evaluating elevated risk of higher AHIs specifically in males.

Regarding the correlation analysis of cephalometric parameters and $LSaO_2$, we found that U-MPW, H1-VC3C4, H3-MP and H3-Go are statistically significant in male group, which is similar to the results on AHI. However, only H3-PtPtm, an indicator of posterior positioned hyoid bone, is significant in the female group.

Previous studies have consistently reported a higher prevalence and severity of OSA in males compared to females, which can be affected by sex hormones, body fat distribution patterns, neck circumference, and central ventilatory control [39, 40]. It's quite intriguing to find out that a gender-dependent pattern also extends to the association between cephalometric parameters related to upper airway morphology and hyoid bone position with OSA severity in adult individuals. Previous studies have revealed that OSA patients presented a lower hyoid position compared to control groups, and hyoid bone is positioned more superiorly and posteriorly in females than males among different skeletal patterns [14, 41, 42]. Similarly, we noticed that H3-PtPtm, a parameter associated with the horizontal position of the hyoid bone, was correlated with $LSaO_2$ in female patients. However, a significant correlation between vertical position of hyoid bone and $LSaO_2$ was only observed in male patients (Table 4). This suggests that the horizontal position of the hyoid bone may also reflects OSA severity in a gender-specific pattern. Further studies should investigate whether the divergence in cephalometric parameters between males and females contributes to the differential clinical manifestations of OSA.

Interestingly, none of the statistically significant AHI-related parameters are present in the correlation analysis of $LSaO_2$ in females, which suggests that different measurements should be considered to evaluate the apnea-hypopnea frequency and hypoxia risk in female individuals. In the multiple regression analysis, only H1-VC3C4 is recognized as statistically significant in predicting both AHI and $LSaO_2$ in males. Additionally, a negative correlation is observed between H3-Me-Go and $LSaO_2$, indicating that an increased distance from hyoid bone to mandible is associated with decreased oxygen saturation levels. Although all models pass F examination effectively, the relatively low R^2 value across all groups indicates that the upper airway and hyoid bone-related cephalometric parameters can only explain a moderate portion of changes in AHI and $LSaO_2$. Recent studies have shown that reduced nocturnal oxygen saturation not only reflects the severity of OSA, but also increases the severity of systemic diseases related to OSA as an

independent risk factor. Mahmoud et al. found that nocturnal hypoxemia but not AHI, was correlated with glycosylated hemoglobin levels in OSA patients combined with type II diabetes mellitus [43]. Similar results were also observed in patients suffering from pulmonary and cardiovascular diseases, emphasizing the advantage of hypoxia-related indicators in capturing the depth of OSA-related symptoms compared to conventional "frequency-based" metrics like AHI [44, 45]. Therefore, investigating whether there is any hypoxemia-related cephalometric parameter is of great clinical significance. Our results indicate that while some cephalometric parameters are correlated with both AHI and $LSaO_2$, there are also $LSaO_2$-specific parameters that can be utilized to predict the severity of OSA-related complications when no abnormalities are present in AHI-related parameters.

According to the American Academy of Sleep Medicine Clinical Practice Guideline, the primary healthcare provider to diagnose and treat OSA patients should be a sleep medicine specialist. Therefore, it appears that orthodontists are not necessarily involved in the diagnosis and management of OSA [46]. However, since many OSA patients seek orthodontic treatment for malocclusion, it's quite easy for orthodontists to identify the risk of OSA by evaluating the clinical symptoms and through radiological examinations such as lateral cephalogram [47]. When performing cephalometric analysis, orthodontists can readily evaluate the patient's craniofacial morphological features while simultaneously predicting the risk of OSA. In addition, orthodontists have the responsibility to consider the effect of orthodontic or orthognathic intervention on the prognosis of OSA. Although maxillomandibular advancement surgery has proven successful in treating OSA surgically, its association with orthognathic surgery, higher cost as well as the consequent change in profile often discourages patients from selecting this approach [48, 49]. In contrast, mandibular advancement devices demonstrate efficacy for certain patients, but their side effects such as pain and temporomandibular discomfort, protrusion of lower incisors and appearance of lateral gaps relegate them to a last-resort status [50, 51]. Other orthodontic treatments for OSA such as maxillary expansion either lack sufficient reliability or require long-term clinical follow up [52, 53]. Therefore, based on previous research and the results of this study, we suggest that orthodontists should pay closer attention to the cephalometric parameters related to upper airway morphology and hyoid-bone position-especially those related to AHI and $LSaO_2$ levels. If the cephalometric analysis implies a higher risk of OSA, it is advisable for the orthodontist to consider recommending the patient to consult a sleep specialist for further advice.

Limitations

There are several limitations of our study. Firstly, all the subjects were Chinese patients, and the sample size was small. Besides, given that this study was designed as a retrospective study, our examination was confined to the accessible data, specifically lateral cephalograms and PSG reports, which precluded the inclusion of a control group. Furthermore, there were uncontrolled variables such as weight, height, lifestyle habits and other socioeconomic factors. Although lateral cephalogram remains valuable for evaluating craniofacial anatomical features due to its ease of use, cost-effectiveness, and widespread availability in many hospitals, its accuracy of diagnosing the widths of respiratory system was insufficient compared with CBCT [54, 55]. In addition, while cephalometric analysis can reflect anatomical characteristics of the craniofacial region, many studies reported inconsistencies in upper airway width changes observed via cephalograms following orthodontic or orthognathic treatment when compared to changes in OSA-severity indicators presented by PSG reports; these discrepancies probably arise from a lack of three-dimensional information [56, 57].

Conclusion

Several cephalometric parameters related to upper airway width and hyoid bone position were correlated with the severity of OSA as indicated by AHI and $LSaO_2$. Some of the parameters were gender-specific. A narrower upper airway width was associated with increased AHI, while a more inferiorly positioned hyoid bone in relation to the mandible was negatively correlated with $LSaO_2$. Our findings highlight the role of key cephalometric parameters in predicting OSA severity based on AHI and $LSaO_2$ levels.

Abbreviations

OSA	Obstructive sleep apnea
AHI	Apnea-hypopnea index
$LSaO_2$	Lowest nocturnal oxygen saturation
PSG	Polysomnography
VIF	Variance inflation factor
IQR	Interquartile range
SD	Standard deviation
AI	Artificial intelligence
H2-S-N	Angle between point H2 and N at S
H3-Me-Go	Angle between point H3 and Go at Me
PNS-UPW	Distance between PNS and UPW
PNS-AD2	Distance between PNS and AD2
U-MPW	Distance between U and MPW
TB-TPPW	Distance between TB and TPPW
V-LPW	Distance between V and LPW
H3-PtPtm	Distance between H3 and line Pt-Ptm
H3-C4	Distance between H3 and C4
H1-VC3C4	Distance between H1 and perpendicular bisector of line C3-C4
H3-MP	Distance between H3 and mandibular plane
H3-Me	Distance between H3 and Me
H3-Go	Distance between H3 and Go

Acknowledgements
We thank the department of radiology in Hospital of Stomatology, Sun Yat-sen University with cephalogram data management.

Author contributions
Z.D: Conceptualization, methodology, writing original draft. Y.Z: Review and editing, investigation, data curation. J.C: Investigation, review and editing. L.W: Review and editing, data curation. H.H: Review and editing; supervision. All authors reviewed the manuscript.

Funding
Not applicable.

Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This study was approved by the Medical Ethics Committee of Hospital of Stomatology, Sun Yat-sen University (Approval No.KQEC-2024-99-01). Informed written consent was obtained from all the patients.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Hospital of Stomatology, Guangdong Provincial Clinical Research Center of Oral Diseases, Sun Yat-sen University, Guangzhou, Guangdong, China
[2]Department of Stomatology, The People's Hospital of Guangxi Zhuang Autonomous Region & Guangxi Academy of Medical Sciences, Nanning, Guangxi, China

Received: 4 September 2024 / Accepted: 7 April 2025
Published online: 17 April 2025

References

1. Benjafield AV, Ayas NT, Eastwood PR, Heinzer R, Ip MSM, Morrell MJ, et al. Estimation of the global prevalence and burden of obstructive sleep apnoea: a literature-based analysis. Lancet Respir Med. 2019;7(8):687–98.
2. Magnusdottir S, Hill EA. Prevalence of obstructive sleep apnea (OSA) among preschool aged children in the general population: A systematic review. Sleep Med Rev. 2024;73:101871.
3. Torres G, Sánchez-de-la-Torre M, Barbé F. Relationship between OSA and hypertension. Chest. 2015;148(3):824–32.
4. Kanclerska J, Wieckiewicz M, Nowacki D, Szymanska-Chabowska A, Poreba R, Mazur G, et al. Sleep architecture and vitamin D in hypertensives with obstructive sleep apnea: A polysomnographic study. Dent Med Probl. 2024;61(1):43–52.
5. Muntz H, Wilson M, Park A, Smith M, Grimmer JF. Sleep disordered breathing and obstructive sleep apnea in the cleft population. Laryngoscope. 2008;118(2):348–53.
6. Lal C, White DR, Joseph JE, van Bakergem K, LaRosa A. Sleep-disordered breathing in down syndrome. Chest. 2015;147(2):570–9.
7. Fernandez-Mendoza J, He F, Calhoun SL, Vgontzas AN, Liao D, Bixler EO. Association of pediatric obstructive sleep apnea with elevated blood pressure and orthostatic hypertension in adolescence. JAMA Cardiol. 2021;6(10):1144–51.
8. Smith DL, Gozal D, Hunter SJ, Philby MF, Kaylegian J, Kheirandish-Gozal L. Impact of sleep disordered breathing on behaviour among elementary school-aged children: a cross-sectional analysis of a large community-based sample. Eur Respir J. 2016;48(6):1631–9.
9. Lyons MM, Bhatt NY, Pack AI, Magalang UJ. Global burden of sleep-disordered breathing and its implications. Respirology. 2020;25(7):690–702.
10. Lévy P, Kohler M, McNicholas WT, Barbé F, McEvoy RD, Somers VK, et al. Obstructive sleep Apnoea syndrome. Nat Rev Dis Primers. 2015;1:15015.
11. Kukwa W, Migacz E, Lis T, Ishman SL. The effect of in-lab polysomnography and home sleep polygraphy on sleep position. Sleep Breath. 2021;25(1):251–5.
12. Smardz J, Martynowicz H, Wojakowska A, Michalek-Zrabkowska M, Mazur G, Wieczorek T, et al. The meaning of the masticatory muscle tonic-type electromyographic pathway correlated with sleep Bruxism and sleep-related breathing disorders - A polysomnographic study. Sleep Med. 2020;68:131–7.
13. Lv R, Liu X, Zhang Y, Dong N, Wang X, He Y, et al. Pathophysiological mechanisms and therapeutic approaches in obstructive sleep apnea syndrome. Signal Transduct Target Ther. 2023;8(1):218.
14. Jo JH, Park JW, Jang JH, Chung JW. Hyoid bone position as an indicator of severe obstructive sleep apnea. BMC Pulm Med. 2022;22(1):349.
15. Neelapu BC, Kharbanda OP, Sardana HK, Balachandran R, Sardana V, Kapoor P, et al. Craniofacial and upper airway morphology in adult obstructive sleep apnea patients: A systematic review and meta-analysis of cephalometric studies. Sleep Med Rev. 2017;31:79–90.
16. Finke H, Drews A, Engel C, Koos B. Craniofacial risk factors for obstructive sleep apnea-systematic review and meta-analysis. J Sleep Res. 2024;33(1):e14004.
17. Armalaite J, Lopatiene K. Lateral teleradiography of the head as a diagnostic tool used to predict obstructive sleep apnea. Dentomaxillofac Radiol. 2016;45(1):20150085.
18. Signorelli L, Patcas R, Peltomäki T, Schätzle M. Radiation dose of cone-beam computed tomography compared to conventional radiographs in orthodontics. J Orofac Orthop. 2016;77(1):9–15.
19. Gottlieb DJ, Punjabi NM. Diagnosis and management of obstructive sleep apnea: A review. JAMA. 2020;323(14):1389–400.
20. Mediano O, Barceló A, de la Peña M, Gozal D, Agustí A, Barbé F. Daytime sleepiness and polysomnographic variables in sleep Apnoea patients. Eur Respir J. 2007;30(1):110–13.
21. Asano K, Takata Y, Usui Y, Shiina K, Hashimura Y, Kato K, et al. New index for analysis of polysomnography, 'integrated area of desaturation', is associated with high cardiovascular risk in patients with mild to moderate obstructive sleep apnea. Respiration. 2009;78(3):278–84.
22. Wang L, Wei DH, Zhang J, Cao J. Time under 90% oxygen saturation and systemic hypertension in patients with obstructive sleep apnea syndrome. Nat Sci Sleep. 2022;14:2123–32.
23. Pae EK, Lowe AA, Sasaki K, Price C, Tsuchiya M, Fleetham JA. A cephalometric and electromyographic study of upper airway structures in the upright and supine positions. Am J Orthod Dentofac Orthop. 1994;106(1):52–9.
24. Duarte RLM, Magalhães-da-Silveira FJ, Gozal D. Screening for obstructive sleep apnea: comparing the American academy of sleep medicine proposed criteria with the STOP-Bang, NoSAS, and GOAL instruments. J Clin Sleep Med. 2023;19(7):1239–46.
25. Jiang F, Guo Y, Yang C, Zhou Y, Lin Y, Cheng F, et al. Artificial intelligence system for automated landmark localization and analysis of cephalometry. Dentomaxillofac Radiol. 2023;52(1):20220081.
26. Udayakumar SIV, Jo HJ, Kim HY, Joo EY, Paeng JY. Gender differences in the upper airway, craniofacial morphological and polysomnographic parameters in patients with obstructive sleep Apnoea. J Oral Rehabil. 2024;51(3):581–92.
27. Peppard PE, Young T, Barnet JH, Palta M, Hagen EW, Hla KM. Increased prevalence of sleep-disordered breathing in adults. Am J Epidemiol. 2013;177(9):1006–14.
28. Redline S, Azarbarzin A, Peker Y. Obstructive sleep Apnoea heterogeneity and cardiovascular disease. Nat Rev Cardiol. 2023;20(8):560–73.
29. Monna F, Ben Messaoud R, Navarro N, Baillieul S, Sanchez L, Loiodice C, et al. Machine learning and geometric morphometrics to predict obstructive sleep apnea from 3D craniofacial scans. Sleep Med. 2022;95:76–83.
30. Kulkas A, Tiihonen P, Julkunen P, Mervaala E, Töyräs J. Novel parameters indicate significant differences in severity of obstructive sleep apnea with patients having similar apnea-hypopnea index. Med Biol Eng Comput. 2013;51(6):697–708.
31. Fernandes ER, Pires GN, Andersen ML, Tufik S, Rosa DS. Oxygen saturation as a predictor of inflammation in obstructive sleep apnea. Sleep Breath. 2022;26(4):1613–20.
32. Park JW, Almeida FR. Disparities in oxygen saturation and hypoxic burden levels in obstructive sleep Apnoea patient's response to oral appliance treatment. J Oral Rehabil. 2022;49(6):633–43.
33. Xu Q, Wang X, Li N, Wang Y, Xu X, Guo J. Craniofacial and upper airway morphological characteristics associated with the presence and severity of obstructive sleep apnea in Chinese children. Front Pediatr. 2023;11:1124610.

34. Johal A, Conaghan C. Maxillary morphology in obstructive sleep apnea: a cephalometric and model study. Angle Orthod. 2004;74(5):648–56.
35. Nassi-Liberman O, Oberman B, Strahl T, Yosef N, Shlomi D. Association between obstructive sleep apnea (OSA) and COVID-19 severity. Journal of Sleep Research.n/a(n/a):e14260.
36. Al Maaitah EF, Al-Musfir TM, Al Jawad FA, NajahAbu Alhaija E, Saleh. Upper airway dimensions and the skeletal parameters in orthodontic patients who developed moderate-severe COVID-19 symptoms during the pandemic. Dent Med Probl. 2023;60(1):13–22.
37. Jadoul M, Albert A, Maes N, Poirrier R, Poirrier AL, Bruwier A. Three-dimensional cone beam computed tomography analysis of craniofacial phenotype in Nonobese apneic young adults. Laryngoscope Investig Otolaryngol. 2025;10(1):e70061.
38. Stipa C, Cameli M, Sorrenti G, Ippolito DR, Pelligra I, Alessandri-Bonetti G. Relationship between cephalometric parameters and the apnoea-hypopnoea index in OSA patients: a retrospective cohort study. Eur J Orthod. 2020;42(1):101–6.
39. Bixler EO, Vgontzas AN, Lin HM, Ten Have T, Rein J, Vela-Bueno A, et al. Prevalence of sleep-disordered breathing in women: effects of gender. Am J Respir Crit Care Med. 2001;163(3 Pt 1):608–13.
40. Chang ET, Wang HM, Lai HL. Gender differences in obstructive sleep apnea syndrome. Eur J Intern Med. 2016;33:e9–10.
41. Wu S, Wang T, Kang X, Wang X, Jiao Y, Du X, et al. Hyoid bone position in subjects with different facial growth patterns of different dental ages. Cranio. 2023;41(5):454–60.
42. 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.
43. Mahmoud MI, Alotaibi RK, Almusally R, Shafiek H, Elamin Y, Alhaj Z, et al. Effect of nocturnal hypoxemia on glycemic control among diabetic Saudi patients presenting with obstructive sleep apnea. Front Endocrinol (Lausanne). 2022;13:1020617.
44. Martinez-Garcia MA, Sánchez-de-la-Torre M, White DP, Azarbarzin A. Hypoxic burden in obstructive sleep apnea: present and future. Arch Bronconeumol. 2023;59(1):36–43.
45. Trzepizur W, Blanchard M, Ganem T, Balusson F, Feuilloy M, Girault JM, et al. Sleep Apnea-Specific hypoxic burden, symptom subtypes, and risk of cardiovascular events and All-Cause mortality. Am J Respir Crit Care Med. 2022;205(1):108–17.
46. Kapur VK, Auckley DH, Chowdhuri S, Kuhlmann DC, Mehra R, Ramar K, et al. Clinical practice guideline for diagnostic testing for adult obstructive sleep apnea: an American academy of sleep medicine clinical practice guideline. J Clin Sleep Med. 2017;13(3):479–504.
47. Lyons-Coleman M, Bates C, Barber S. Obstructive sleep Apnoea and the role of the dental team. Br Dent J. 2020;228(9):681–5.
48. Dicus Brookes CC, Boyd SB. Controversies in obstructive sleep apnea surgery. Oral Maxillofac Surg Clin North Am. 2017;29(4):503–13.
49. Shi P, Huang Y, Kou H, Wang T, Chen H. Risk factors for facial appearance dissatisfaction among orthognathic patients: comparing patients to a Non-Surgical sample. Front Psychol. 2019;10:2775.
50. Chen A, Burger MS, Rietdijk-Smulders MAWJ, Smeenk FWJM. Mandibular advancement device: effectiveness and dental side effects. A real-life study. Cranio: J Craniomandib Pract. 2020;5:1–10.
51. Baldini N, Gagnadoux F, Trzepizur W, Meslier N, Dugas J, Gerves-Pinquie C, et al. Long-term dentoskeletal side effects of mandibular advancement therapy in patients with obstructive sleep apnea: data from the pays de La Loire sleep cohort. Clin Oral Invest. 2022;26(1):863–74.
52. Hamoda MM, Kohzuka Y, Almeida FR. Oral appliances for the management of OSA: an updated review of the literature. Chest. 2018;153(2):544–53.
53. Xie B, Zhang L, Lu Y. The role of rapid maxillary expansion in pediatric obstructive sleep apnea: efficacy, mechanism and multidisciplinary collaboration. Sleep Med Rev. 2023;67:101733.
54. Eslami E, Katz ES, Baghdady M, Abramovitch K, Masoud MI. Are three-dimensional airway evaluations obtained through computed and cone-beam computed tomography scans predictable from lateral cephalograms? A systematic review of evidence. Angle Orthod. 2017;87(1):159–67.
55. Hsu WE, Wu TY. Comparison of upper airway measurement by lateral cephalogram in upright position and CBCT in supine position. J Dent Sci. 2019;14(2):185–91.
56. Vejwarakul W, Ko EW, Lin CH. Evaluation of pharyngeal airway space after orthodontic extraction treatment in class II malocclusion integrating with the subjective sleep quality assessment. Sci Rep. 2023;13(1):9210.
57. Butterfield KJ, Marks PL, McLean L, Newton J. Linear and volumetric airway changes after maxillomandibular advancement for obstructive sleep apnea. J Oral Maxillofac Surg. 2015;73(6):1133–42.

Publisher's note