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Obstructive Sleep Apnea Prevalence, Upper Airway Dimensions, and Sleep Parameters in Skeletal Class III Malocclusion Patients Undergoing Orthognathic Surgery with Different Vertical Skeletal Patterns

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Abstract

Background: Craniofacial morphology's relationship with airway dimensions has been extensively studied. Despite this, evidence regarding obstructive sleep apnea (OSA) prevalence and differences in airway dimensions among vertical skeletal patterns in skeletal Class III malocclusion patients undergoing orthognathic surgery is limited. **Objective:** To determine the prevalence of OSA and compare upper airway dimensions and sleep parameters among skeletal Class III patients with different vertical skeletal patterns. **Materials and methods:** The study involved 98 adult patients (39 male and 59 female) with skeletal Class III malocclusions undergoing orthognathic surgery. Patients were divided into three groups according to vertical skeletal patterns: high-angle (SN-GoGn > 33°; 47 patients), low-angle (SN-GoGn < 25°; 20 patients), and normal-angle (SN-GoGn 25-33°; 31 patients) groups. OSA prevalence and sleep parameters, including the apnea-hypopnea index and lowest oxygen saturation, were assessed using a portable level III polysomnography device. Cone beam computed tomography was performed, and upper airway dimensions, including nasopharyngeal, oropharyngeal, hypopharyngeal, and total upper airway volumes and minimum cross-sectional area, were measured using Dolphin Imaging software. Group differences were analyzed using ANOVA and post hoc Tukey tests ($P < 0.05$). **Results:** The prevalence of OSA among skeletal Class III malocclusion patients was 11 of 98 (11.22 %). Upper airway dimensions and sleep parameters did not differ significantly among vertical skeletal pattern groups. **Conclusion:** Despite a comparable OSA prevalence in skeletal Class III patients, screening for OSA is crucial in those with Class III malocclusion undergoing mandibular setback surgery, irrespective of vertical patterns.

Keywords: Class III malocclusion, Obstructive sleep apnea, Sleep parameters, Upper airway, Vertical skeletal patterns

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Introduction

Skeletal Class III malocclusion is characterized by the presence of mandibular prognathism, maxillary retrognathism, or a combination of both. For non-growing patients with moderate to severe skeletal Class III malocclusion, a combination of orthodontic treatment and orthognathic surgery is preferred.[1] Orthognathic surgery that moves maxillomandibular structures can affect skeletal structures and related soft tissues, including the soft palate, tongue, and epiglottis. Two systematic reviews of airway changes after mandibular setback surgery have shown a significant decrease in the upper airway volume.[2,3] Moreover, some recent studies have reported that patients with a large mandibular setback can develop obstructive sleep apnea (OSA).[4,5]

OSA is the most common sleep breathing disorder and is characterized by repeated episodes of partial or complete obstructions in the upper airway during sleep, resulting in reduced oxygen saturation (SpO_2). OSA is associated with increased morbidity and mortality.[6,7] Polysomnography (PSG), which simultaneously monitors various sleep and respiratory parameters, is used to diagnose OSA and assess its severity. One parameter measured is the apnea-hypopnea index (AHI), which assesses the mean number of apneas and hypopneas per hour of sleep. Adult OSA can be categorized as mild (AHI from 5 to < 15 events/hour), moderate (AHI from 15 to < 30 events/hour), or severe (AHI $\geq$ 30 events/hour).[7] The anatomical structure of the upper airway and craniofacial region plays an important role in OSA development.[8,9] Craniofacial morphologies, including retrognathia, long and narrow faces, dolichocephalic facial type, narrow and deep palate, steep mandibular plane angle, anterior open bite, midface deficiency, and lower hyoid position, are predisposing factors for OSA.[10]

Among adults in the general population, the prevalence of OSA varies from 9 % to 38 %.[11] The prevalence of OSA in the Thai population is 11.40 %.[12] Positive correlations of increased age, male gender, and increased body mass index (BMI) with the occurrence of OSA were confirmed by a systematic review.[11] Among patients with OSA, one study found that the most frequent sagittal skeletal classification was Class II at 57.20 % and that the least frequent was Class III at 10.50 %, while the most frequent vertical classification was high angle at 54 %, and the least frequent was low angle at 19.30 %.[13] Nevertheless, there is a lack of data required to determine the frequency of OSA in patients with skeletal Class III malocclusion undergoing orthognathic surgery.

The relationship between craniofacial morphology and airway dimensions has been studied for decades. Numerous articles have analyzed the dimensions of the upper airway in patients with different sagittal and vertical skeletal facial morphologies. Cephalometric radiographs have historically been used to measure upper airway dimensions, but this method has some drawbacks, including distortion, low reproducibility due to challenges in identifying landmarks, variation in magnification, superimposition of bilateral craniofacial structures, and a two-dimensional (2D) anteroposterior linear dimension.[14] Airway examination improved with the introduction of cone beam computed tomography (CBCT), which produces more accurate and reliable images, generating more comprehensive data than 2D radiography.[15] Previous CBCT studies of sagittal relationships found that upper airway dimensions were smaller in Class II than in Class I and Class III patients, especially at the oropharyngeal level.[16-19] The results of the previous CBCT studies of the vertical relationship are still controversial. Grauer et al.[16] found no differences in airway volumes related to vertical skeletal patterns. Another study reported that the oropharyngeal and total airway volumes were highest in the low-angle group and lowest in the high-angle group in skeletal Class I patients.[20] However, there is a lack of data on differences in upper airway dimensions and sleep parameters among skeletal Class III patients with differing vertical skeletal patterns.

The aims of the study were as follows: 1) to determine the prevalence of OSA in skeletal Class III

malocclusion patients undergoing orthognathic surgery and 2) to compare upper airway dimensions and sleep parameters among skeletal Class III patients undergoing orthognathic surgery with different vertical skeletal patterns.

Materials and methods

Study design and sample

This study was designed and implemented as an ambispective cohort study. The participants included skeletal Class III malocclusion patients requiring combined orthodontics and orthognathic surgery. Procedures involved both one-jaw, mandibular setback surgery, and two-jaw surgery, which comprised maxillary advancement and/or maxillary posterior impaction combined with mandibular setback from July 2019 to December 2023 at the Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Chiang Mai University, Thailand. Participants were included according to the following criteria: Thai nationality; age 18 years or older; skeletal Class III malocclusion (ANB < 1.80 degrees; normal 3.80 ± 2.00 degrees);[21] undergoing combined orthodontics and orthognathic surgery; and good general health, according to the American Society of Anesthesiologists (ASA), at either ASA I or ASA II. Individuals were excluded if they had craniofacial syndromes, trauma, or pharyngeal or nasal pathology. The selected patients were divided into three groups based on vertical skeletal patterns using the SN-GoGn angle (high angle > 33 degrees, low angle < 25 degrees, and normal angle 25-33 degrees).[21] The Ethics Committee for Research Involving Human Experimentation Committee of the Faculty of Dentistry, Chiang Mai University, reviewed and approved the present study (No. 55/2022). All patients signed an informed consent form allowing use of their data for scientific purposes.

A pilot study was conducted to determine the minimum sample size. G*Power software version 3.1.9.4 (University of Kiel, Kiel, Germany) was used to calculate the sample size. Considering a power of 90 %, $P < 0.05$, and an effect size of 0.52, the final sample included 17 participants in each group.

CBCT image acquisition and upper airway volume assessment

Before orthognathic surgery, CBCT images were obtained using a mobile CBCT scanner, MobiiScan (NSTDA, Bangkok, Thailand), at 90 kV, 8 mA, 22 cm x 18 cm field of view, and 0.40 mm voxel size. Patients were scanned in a supine position. Before CBCT scan acquisition, patients were instructed to bite with maximum intercuspation, to place the tongue against the hard palate, to breathe normally, and not to swallow. The mean timeframe for pre-surgery CBCT scans was 29 days, with variations ranging from 1 to 95 days before the surgery date. The images were stored in Digital Imaging and Communications in Medicine (DICOM) format. To simulate 2D lateral cephalometry from CBCT images and to measure upper airway dimensions, Dolphin Imaging software version 11.90 (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA) was utilized. All CBCT scans were taken and evaluated by a single examiner.

From the CBCT scan of each patient, the plane orientation was conducted manually using the method previously described by Guijarro-Martínez and Swennen.[22] 2D lateral cephalometry was simulated from three-dimensional (3D) CBCT. Linear and angular measurements, including SNA, SNB, ANB, SN-GoGn, and FMA angles, were recorded. The upper airway dimensions, including nasopharyngeal volume, oropharyngeal volume, hypopharyngeal volume, total upper airway volume, and minimum cross-sectional area, were measured using the method of Guijarro-Martínez and Swennen.[22] A threshold value of the upper airway morphology was manually adjusted until the pharyngeal airway was adequately depicted, with an average threshold of 60 (range 53-68). The software automatically calculated the upper airway volume of each component and the total upper airway volume in mm^3 (Figure 1).

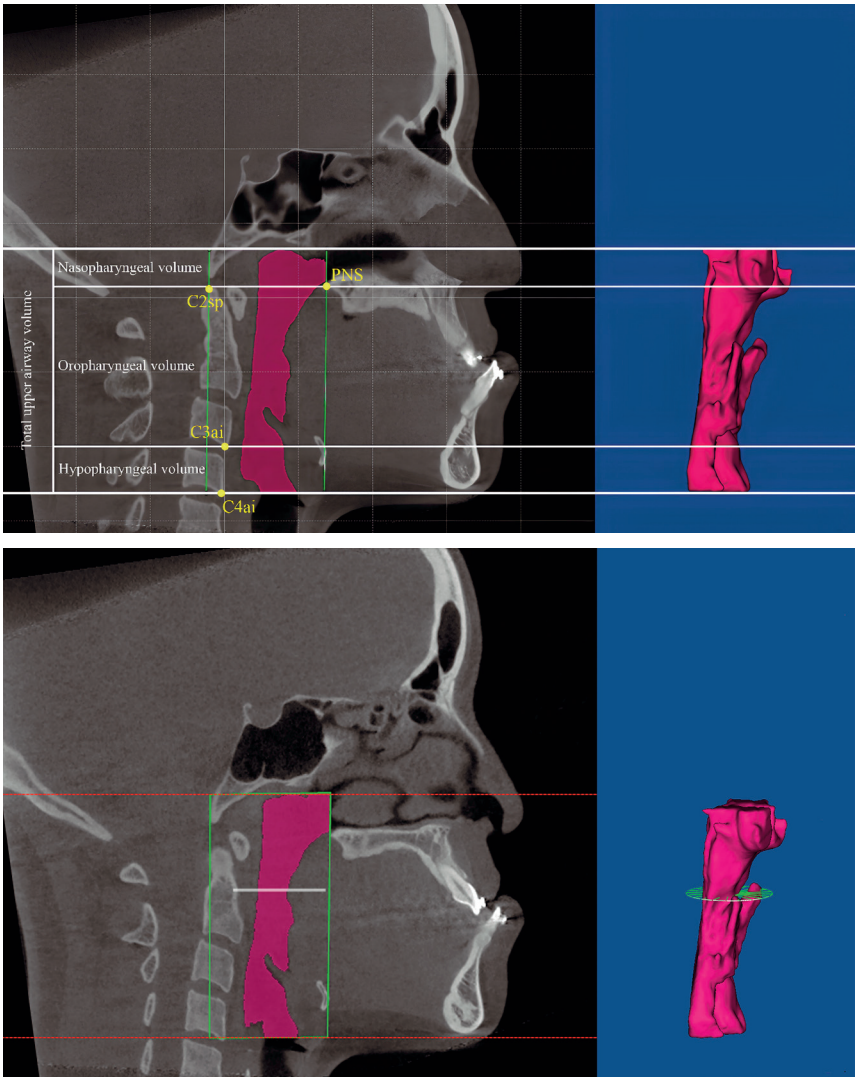

Figure 1 The boundaries of the upper airway dimensions. (A) Nasopharyngeal, oropharyngeal, hypopharyngeal, and total upper airway volume landmarks: posterior nasal spine (PNS), most superoposterior point of the second cervical vertebra (C2sp), most anteroinferior aspect of the third cervical vertebrae (C3ai), and most anteroinferior aspect of the fourth cervical vertebra (C4ai). (B) Minimum cross-sectional area.

Polysomnography evaluation

Before orthognathic surgery, patients were assessed for the sleep parameters monitored by overnight PSG, including AHI and lowest SpO_2, which were measured using a portable level III PSG device, namely, SOMNOlab 2 (Weinmann GmbH, Hamburg, Germany). The average duration for pre-surgery overnight PSG evaluation was 35 days, with a range from 1 to 168 days before the date of surgery. All sleep parameters were interpreted by an experienced otorhinolaryngologist.

Statistical analysis

To determine the intraobserver variability and reproducibility, 10 DICOM files were randomly selected, and upper airway volume was evaluated twice at an interval of 4 weeks by a single inspector. The resulting intraclass correlation coefficient more than 0.90 indicated high reliability. The Statistical Package for the Social Sciences (SPSS) version 24.0 for Windows (SPSS Inc., Chicago, IL, USA) was used to implement all statistical analyses. Descriptive

statistics included the means and standard deviations of variables in all groups. Because the Shapiro-Wilk normality test confirmed a normal distribution of the data, comparisons between the groups were made using parametric tests. The distributions of the gender in each group were analyzed with a χ^2 test, and whether groups differed in chronological age or BMI was tested by one-way analysis of variance (ANOVA). One-way ANOVA was performed to test for potential differences in upper airway volume and sleep parameters among groups, and a post hoc Tukey honestly significant difference test was employed to evaluate individual differences. The results were considered statistically significant if $P < 0.05$.

Results

The overall sample included 98 patients who met the inclusion but not the exclusion criteria. The following demographic characteristics of the sample population were observed: there were 47 patients in the high-angle group (mean age: 22.79 ± 3.77 years; 20 males and 27 females; BMI: 21.09 ± 2.95 kg/m^2), 20 patients in the low-angle group (mean age: 22.50 ± 4.80 years; 11 males and 9 females; BMI: 22.22 ± 3.20 kg/m^2), and 31 patients in the normal-angle group (mean age: 24.71 ± 7.09 years; 8 males and 23 females; BMI: 20.94 ± 3.24 kg/m^2). The comparison of demographic characteristics, (Table 1) including age and BMI, of the sample population in three vertical skeletal patterns showed no significant differences ($P > 0.05$). One cephalometric measurement, ANB angle, showed no significant differences among groups. However, the significant differences ($P < 0.05$) in SNA, SNB, SN-GoGn, and FMA angles were found among groups (Table 1).

The prevalence of OSA severity among skeletal Class III malocclusion patients was 11 of 98 (11.22 %), with 8 (7.14 %) classified as mild severity and 3 (3.06 %) as moderate severity. There were 2 (4.25 %) and 2 (4.25 %) patients with mild and moderate OSA

Table 1 Demographic characteristics and cephalometric measurements in three vertical skeletal patterns.

Mean (SD)	High angle (n = 47)	Low angle (n = 20)	Normal angle (n = 31)	*P* value
Gender (n) Male Female	 20 27	 11 9	 8 23	0.101
Age (years)	22.79 (3.77)	22.50 (4.80)	24.71 (7.09)	0.211
BMI (kg/m^2)	21.09 (2.96)	22.22 (3.20)	20.94 (3.24)	0.308
SNA (degrees)	81.46 (2.74)	85.55 (3.99)	84.89 (3.99)	0.000
SNB (degrees)	84.09 (2.86)	88.95 (5.47)	87.10 (3.45)	0.000
ANB (degrees)	−2.64 (2.16)	−3.42 (3.09)	−2.73 (2.97)	0.526
SN-GoGn (degrees)	37.02 (2.84)	22.39 (2.28)	30.11 (1.93)	0.000
FMA (degrees)	28.43 (3.92)	17.35 (4.36)	23.45 (3.56)	0.000

Table 2 Frequencies and percentages of OSA severity in three vertical skeletal patterns.

OSA severity	High angle (*n* = 47)		Low angle (*n* = 20)		Normal angle (*n* = 31)	
	n	%	*n*	%	*n*	%
Normal	43	91.50	17	85.00	27	87.10
Mild	2	4.25	3	15.00	3	9.68
Moderate	2	4.25	-	-	1	3.22
Severe	-	-	-	-	-	-
Total	47	100	20	100	31	100

Table 3 Comparisons of airway dimensions and sleep parameters in the vertical skeletal patterns.

Mean (SD)	High angle (*n* = 47)	Low angle (*n* = 20)	Normal angle (*n* = 31)	*P* value
Nasopharyngeal volume (mm^3)	7,537.53 (2,461.09)	7,516.65 (2,667.04)	7,141.77 (2,325.74)	0.767
Oropharyngeal volume (mm^3)	15,574.47 (5,767.83)	14,180.05 (4,815.44)	12,993.42 (4,771.49)	0.109
Hypopharyngeal volume (mm^3)	4,743.91 (1,666.41)	5,181.65 (2,060.76)	4,153.32 (1,602.06)	0.108
Total upper airway volume (mm^3)	27,787.30 (8,439.69)	26,878.35 (8,333.62)	24,288.52 (7,185.84)	0.172
Minimum cross-sectional area (mm^2)	85.83 (50.73)	92.80 (61.55)	87.55 (47.15)	0.881
AHI (events/hour)	1.68 (3.77)	1.85 (2.23)	2.18 (3.85)	0.829
Lowest SpO_2	86.91 (5.44)	84.40 (7.30)	86.80 (5.10)	0.236

severity, respectively, in the high-angle group. In the low-angle group, 3 patients (15 %) had mild OSA severity. In the normal-angle group, 3 patients (9.68 %) exhibited mild OSA severity, while 1 (3.22 %) had moderate OSA severity (Table 2).

Table 3 compared airway dimensions and sleep parameters in three vertical skeletal patterns. No statistically significant differences were observed in the nasopharyngeal volume, oropharyngeal volume, hypopharyngeal volume, total upper airway volume, or minimum cross-sectional area across patients with various vertical skeletal patterns ($P > 0.05$). Likewise, there were no statistically significant differences in the AHI or lowest SpO_2 among patients with different vertical skeletal patterns ($P > 0.05$).

Table 4 Comparisons of oropharyngeal and hypopharyngeal volumes between the genders and groups

Mean (SD)	Oropharyngeal volume (mm^3)	*P* value	Hypopharyngeal volume (mm^3)	*P* value
High angle				
Male (*n* = 20)	17,935.85 (6,274.78)		5,740.40 (1,609.76)	
Female (n = 27)	13,825.30 (4,755.98)		4,005.78 (1,299.90)	
Low angle				
Male (*n* = 11)	16,425.18 (4,732.56)	0.003	6,460.09 (1,839.74)	0.000
Female (*n* = 9)	11,436.00 (3,416.75)		3,619.11 (927.99)	
Normal angle				
Male (*n* = 8)	15,000.00 (5,812.02)		5,798.88 (1,741.61)	
Female (*n* = 23)	12,295.48 (4,280.72)		3,580.95 (1,098.92)	

Comparisons of oropharyngeal and hypopharyngeal volumes between the genders are shown in Table 4. Male had higher oropharyngeal and hypopharyngeal volumes than female in all groups ($P < 0.05$). In contrast, there were no statistically significant differences in nasopharyngeal volume, total airway volume, minimum cross-sectional area, or sleep parameters between the genders ($P > 0.05$).

Discussion

The results of this study demonstrated that the overall prevalence of OSA in skeletal Class III malocclusion patients was 11.22 %, and 72.72 % of OSA patients had mild severity. The upper airway dimensions and sleep parameters of skeletal Class III malocclusion patients did not differ significantly among vertical skeletal pattern groups.

Combined orthodontic and orthognathic surgery has proven to be the most effective treatment for moderate to severe skeletal Class III malocclusion. Surgically correcting skeletal deformities in patients with Class III malocclusion involves displacing the maxilla and/or mandible. This surgical intervention changes the relationship between the bony structures and the soft tissues, including those closely associated with the upper airway anatomy.[23] In most studies, undergoing isolated mandibular setback surgery led to a decrease in the nasopharyngeal, oropharyngeal, hypopharyngeal, and total airway volumes.[24-26] Bimaxillary surgery, which includes mandibular setback, has been associated with a reduction in airway volume. However, it is noteworthy that the magnitude of this reduction tends to be less than that observed with isolated mandibular setback surgery.[24,25] The impact of the upper airway anatomy on airway obstruction is widely acknowledged. In individuals with sleep apnea, the upper oropharyngeal airway is typically smaller than in control participants without sleep disorders.[27] Furthermore, recent studies have indicated that a significant mandibular setback can contribute to the development of OSA.[4,5] This underscores the importance of investigating airway dimensions and sleep parameters in this particular group of patients.

Magnetic resonance imaging (MRI), cine-MRI, endoscopy, optical coherence tomography, cephalometry, conventional CT, and CBCT are among the imaging methods used to evaluate the upper airway.[28] Although MRI seems to be the best imaging method for measuring the upper airway, it has numerous disadvantages, such as high cost, limited access, weight restrictions, and difficulty of use in patients who have claustrophobia or metal devices implanted in the body. Since the 1990s, CBCT has been a generally accepted tool for diagnostic and treatment planning in orthodontics and oral and maxillofacial surgery. Compared to traditional CT, CBCT provides a few benefits, such as less radiation exposure, lower prices, higher accessibility, and faster acquisition times.[28] In numerous studies, CBCT also was shown to be precise and reliable for analysis of the upper airways.[28-30] Therefore, CBCT was used in the present study.

The current study focused on recording upper airway data when patients were in a resting supine position, which is considered to better simulate a patient's sleep posture than other positions. Additionally, the supine position often triggers symptoms of OSA. A study by Joosten et al.[31] highlighted that supine OSA is a major characteristic of the OSA syndrome, potentially explaining why the supine position is particularly conducive to upper airway collapse. This rationale supports the decision to conduct measurements while patients were in a supine body position.

The 3D software used in the present study, Dolphin Imaging, has been shown to be both accurate and reliable in the measurement of upper airway dimensions.[28,32] Among its advantages are the abilities for the user to manually change the threshold values and to evaluate reconstructions in three dimensions (axial, coronal, and sagittal). However, the high cost of the software and the incompatibility of its sensitivity threshold with other image software options are limitations.[32]

In this study, level III PSG was employed to measure sleep parameters. Level III PSG relies on a portable device to monitor at least four parameters.[33] This option was introduced as a more accessible and less expensive alternative to in-laboratory PSG. Moreover, the examination is performed in a more relaxed and natural environment than in-laboratory PSG. According to a systematic review and meta-analysis, level III portable devices demonstrated good diagnostic performance in comparison to level I sleep tests in adult patients with a high pretest probability of moderate to severe OSA and no unstable comorbidities.[34]

Kim et al.[13] reported that, in OSA patients, the sagittal skeletal classification had a frequency distribution of 32.30 % for Class I, 57.20 % for Class II, and 10.50 % for Class III malocclusion. The distribution of vertical classification was 26.70 % for normodivergent, 54 % for hyperdivergent, and 19.30 % for hypodivergent types. Class II hyperdivergent patients have the highest chance of experiencing OSA. Moreover, when considering only the sagittal skeletal relationship, it becomes evident that Class III patients are less likely to have OSA. The current study discovered that the prevalence of OSA among skeletal Class III patients was 11.22 %, which does not differ from the rates observed in the general population (ranging from 9 % to 38 %)[11] or the general Thai population (11.40 %).[12]

Few studies have reported airway volume in patients with different vertical skeletal patterns. In individuals not classified by sagittal skeletal relationships, Grauer et al.[16] found that there were no significant differences in the nasopharyngeal, oropharyngeal, hypopharyngeal, or total airway volumes among the high-angle, normal-angle, and low-angle groups. It is evident from both past studies and the present study that different vertical skeletal patterns have diverse impacts on the upper airway within each group of patients categorized by sagittal skeletal relationships. Wang et al.[35] reported that, in individuals with a skeletal Class II relationship, the

high-angle group had significantly lower glossopharynx volume than normal-angle and low-angle groups, respectively. In contrast, another study reported that, among skeletal Class I patients, oropharyngeal and total airway volumes were highest in the low-angle group and lowest in the high-angle group.[20] In the current study involving skeletal Class III patients, we found no significant differences in pharyngeal airway volume measurements among the groups with different vertical skeletal patterns.

Insufficient evidence exists to establish an association between sleep parameters and various craniofacial morphologies, including both sagittal and vertical skeletal relationships. The current study found that a variety of vertical skeletal patterns in Class III malocclusion patients did not impact sleep parameters, including AHI and lowest SpO_2. However, additional study is imperative to explore sleep parameters within groups of patients exhibiting diverse craniofacial structures.

In the current study, male with skeletal Class III malocclusion exhibited significantly larger oropharyngeal and hypopharyngeal volumes than female. This aligns with the findings of Chiang et al.,[36] who also identified a significant gender-related difference in airway volume. Another study[37] observed a noteworthy gender-related difference in airway volumes, specifically in the retropalatal and retroglossal regions within the Class III group, but no significant difference was noted in nasopharyngeal airway volumes. However, no significant gender differences in airway volumes were found in various other previous studies.[16,19,20] The observed variation in various characteristics among studies, such as differences in sample size, gender distribution, age distribution, and the utilization of distinct anatomical landmarks to define the airway, suggests that these factors could be contributing to the differences in results. These methodological distinctions may impact the interpretation and comparison of outcomes across studies.

Another noteworthy consideration is that previous research has highlighted disparities in the upper airway characteristics between individuals with and without OSA.[38] It would be intriguing to explore within-group differences between subjects with and without OSA in further studies. This comparative analysis could offer valuable insights into the distinct features of the upper airway associated with OSA.

In clinical practice, before commencing treatment for skeletal Class III malocclusion patients, particularly those necessitating mandibular setback surgery, it is essential to conduct screening for OSA. This is crucial in enabling orthodontists and maxillofacial surgeons to identify the most effective treatment approach that minimally impacts upper airway dimensions and preserves sleep quality.

Conclusion

The upper airway dimensions and sleep parameters of skeletal Class III malocclusion patients did not differ significantly among vertical skeletal pattern groups. However, despite the prevalence of OSA in skeletal Class III patients being 11.22 %, a figure not significantly different from rates observed in the general population, it remains crucial to conduct screening for OSA in skeletal Class III malocclusion patients undergoing mandibular setback surgery.

Author contributions

TK: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing-Original Draft, Writing-Review & Editing, and Visualization; NS: Conceptualization, Investigation, Resources, Writing-Review & Editing, and Supervision; KT: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Writing-Review & Editing, Visualization, Supervision, Project administration, and Funding acquisition.

Ethical statement

The research protocol was approved by the Ethics Committee of the Faculty of Dentistry, Chiang Mai University (No. 55/2022).

Disclosure statement

Authors have no the conflict of interest.

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