Sleep and Breathing (2023) 27:631–640
https://doi.org/10.1007/s11325-022-02664-5

SLEEP BREATHING PHYSIOLOGY AND DISORDERS • ORIGINAL ARTICLE

Associations of overnight changes in body composition with positional obstructive sleep apnea

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Received: 7 October 2021 / Revised: 12 April 2022 / Accepted: 9 June 2022 / Published online: 25 June 2022

Abstract

Purpose Body composition is considered to be associated with obstructive sleep apnea (OSA) severity. This cross-sectional study aimed to examine associations of overnight body composition changes with positional OSA.

Methods The body composition of patients diagnosed with non-positional and positional OSA was measured before and after overnight polysomnography. Odds ratios (ORs) of outcome variables between the case (positional OSA) and reference (non-positional OSA) groups were examined for associations with sleep-related parameters and with changes in body composition by a logistic regression analysis.

Results Among 1584 patients with OSA, we used 1056 patients with non-positional OSA as the reference group. We found that a 1-unit increase in overnight changes of total fat percentage and total fat mass were associated with 1.076-fold increased OR (95% confidence interval (CI): 1.014, 1.142) and 1.096-fold increased OR (95% CI: 1.010, 1.189) of positional OSA, respectively (all $p < 0.05$). Additionally, a 1-unit increase in overnight changes of lower limb fat percentage and upper limb fat mass were associated with 1.043-fold increased OR (95% CI: 1.004, 1.084) and 2.638-fold increased OR (95% CI: 1.313, 5.302) of positional OSA, respectively (all $p < 0.05$). We observed that a 1-unit increase in overnight changes of trunk fat percentage and trunk fat mass were associated with 1.056-fold increased OR (95% CI: 1.008, 1.106) and 1.150-fold increased OR (95% CI: 1.016, 1.301) of positional OSA, respectively (all $p < 0.05$).

Conclusion Our findings indicated that nocturnal changes in the body's composition, especially total fat mass, total fat percentage, lower limb fat percentage, upper limb fat mass, trunk fat percentage, and trunk fat mass, may be associated with increased odds ratio of positional OSA compared with non-positional OSA.

Keywords Apnea–hypopnea index (AHI) · Arousal · Body fluid · Fat distribution · Muscle distribution · Upper airway

Introduction

Previous studies have reported that the body's position during sleep can predispose approximately 35 ~ 56% of patients to experience obstructive sleep apnea (OSA) [1, 2]. Positional OSA is defined as ≥ 5 events/h of the overall apnea–hypopnea index (AHI), with the AHI in the supine position being at least two times higher than the AHI in non-supine positions (i.e., lateral and prone positions) [2, 3]. Non-positional OSA is defined as ≥ 5 events/h of the overall AHI, with AHI in the supine position being less than twice that in the non-supine position [3]. We defined more severe positional OSA as a higher ratio of AHI in the supine position/AHI in the non-supine positions. Previous findings showed that patients with positional OSA had better sleep quality and less daytime sleepiness when they changed to a lateral sleeping posture [4]. In patients with positional OSA, gravitational effects in the supine position may facilitate collapse of the upper airway [5], which is associated with increased apneic events [3]. However, associations between body composition parameters and positional OSA remain unknown.

Bioelectrical impedance technique estimates body composition by calculating the impedance of the body as a conductor to an electric current passing through the human body [6–8]. The principle of BIA analysis is that electric

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current passes through the body at different rates depending on its composition. The human body is composed mostly of water with ions, especially in the muscle tissue, which provides better electrical conductivity. On the other hand, the human body also contains body fat, which is the less-conducting material that creates resistance to electric current flow. Based on the difference in impedance of various body compositions, the total fat-free mass, total fat mass, total muscle mass, and total body water are calculated.

Body composition has been linked to OSA severity [9]. Specifically, a high total fat mass has been associated with an increased AHI [10]. On the other hand, a low total muscle mass was observed in subjects with severe OSA compared to a control group [11]. A previous study found an inverse correlation between the fat-free mass and the AHI ($r = -0.92$, $p < 0.05$) [12]. Furthermore, overnight body composition changes, especially in the fat percentage and fat mass of the legs, arms, and trunk, have been associated with OSA severity [13]. Taken together, we hypothesized that changes in the overnight body composition may be associated with positional OSA. The objective of this study was to investigate associations of nocturnal changes in the body composition with positional OSA.

Materials and methods

Study subjects

We conducted a cross-sectional study, consisting of subjects with OSA recruited from a sleep center in New Taipei City, Taiwan, from 1 May 2019 to 15 January 2021. The inclusion criteria were subjects aged 18 ~ 90 years and diagnosed with OSA (overall AHI of ≥ 5 events/h) by full-night polysomnography (PSG). We excluded patients with chronic obstructive pulmonary disease, heart failure, cardiovascular diseases, diabetes mellitus, venous insufficiency, renal failure, and patients undergoing hemodialysis. Participants who slept less than 15 min in the supine and non-supine positions (i.e., lateral and prone positions) were excluded as previously reported [14, 15]. Sleep parameters of each subject were investigated by overnight PSG, while the measurement of the body composition was conducted before (21:00 ~ 22:00) and after sleep (the next morning 06:00 ~ 07:00). The study protocol (TMU-JIRB no. N201912095) was approved by the Taipei Medical University (Taipei, Taiwan) joint institutional review board (JIRB).

Body composition

Tanita MC-780 bioelectric impedance system (Tanita, Tokyo, Japan) was used to conduct pre- and post-sleep measurements of the body's composition, as previously described [13, 16]. Briefly, participants were required to avoid eating and engaging in physical exercise for at least 3 h before the measurement. Next, subjects emptied their bladder, stood on the electrode platform in their bare feet, and held the detection handles. Their arms were kept straight down and their inner thighs were kept from touching each other. The post-sleep measurements were executed immediately after subjects had awakened the next morning. Participants were not permitted to eat or drink between the two body composition evaluations. All tests were conducted by certified sleep technicians.

The Tanita MC-780 is an 8 electrode multi-frequency segmental body composition analyzer that can measure left, right, and trunk segmental composition [17, 18]. It assumes body in the shape of 5 discrete cylinders (i.e., right arm, left am, trunk, right leg, and left leg). Therefore, the system can measure both total and segmental body composition. It was considered a simple and reproducible method to assess body composition and could be compared with dual x-ray absorptiometry (DXA) [19, 20]. Total body fat, fat-free mass, body water, segmental fat mass, and segmental fat-free mass values (i.e., right arm, left am, trunk, right leg, and left leg) were indicated on the digital screen by the end of the analysis. The basal metabolic rate (BMR) was calculated by the system [21]. Meanwhile, metabolic age is calculated by comparing personal BMR to the BMR average of the same chronological age group [21].

Sleep parameters

Participants underwent an overnight PSG analysis using the Embla N7000 (Medcare, Reykjavik, Iceland) digital PSG system, with Somnologica analytical software (Medcare). The scoring of sleep stages and sleep arousals was conducted in accordance with the American Academy of Sleep Medicine (AASM) 2007 guideline [22, 23]. Sleep-related parameters collected by PSG included the sleep efficiency, total sleep time (TST), wake time after sleep onset (WASO), snoring index, the AHI, the AHI in the non-rapid eye movement (NREM) stage, the AHI in the rapid eye movement (REM) stage, the percentage of the TST in the NREM sleep stage I (N1%), the percentage of the TST in the NREM sleep stage II (N2%), the percentage of the TST in the NREM sleep stage III (N3%), the percentage of the TST in the REM sleep stage (REM%), the total arousal index, the total arousal index in the NREM sleep stage, the total arousal index in the REM sleep stage, mean arterial oxygen saturation (SaO_2), time spent in the supine position, the supine AHI, and the non-supine AHI. The AHI was measured as the total number of apneic and hypopneic events per sleep hour (events/h). SaO_2 was determined by pulse oximetry.

Statistical analysis

Tests of normality were used to identify if the data had a normal distribution. To minimize the influence of outliers, extreme values outside the 1 and 99 percentiles were replaced using a winsorization method [24, 25]. We used independent samples *t* test to compare the variables between positional OSA and non-positional OSA group. Upper limb composition parameters were calculated as left arm plus right arm composition parameters, whereas lower limb composition parameters were determined as left leg plus right leg composition parameters. We used a paired *t* test to compare pre- and post-sleep parameters of the body's composition. Nocturnal body composition changes were calculated as the difference (delta; Δ) in these parameters before and after sleep. The change (Δ) in each body composition was calculated as the pre-sleep parameter minus its post-sleep parameter. Odds ratios (ORs) of outcome variables between the case (positional OSA) and reference (non-positional OSA) groups were examined for associations with sleep-related parameters and with changes in the body composition by a logistic regression analysis. We used multiple linear regression analyses to investigate associations of nocturnal body composition changes with sleep-related parameters in the positional OSA group (Table S3). In both analyses, we adjusted for covariates (age, sex, and body mass index (BMI)). To minimize the influence of OSA severity, we further separated into three subgroups (mild OSA ($5 \le AHI < 15$), moderate OSA ($15 \le AHI < 30$), and severe OSA ($AHI \ge 30$)) and adjusted for baseline OSA severity in the logistic regression analysis (Table S4 and Table S5). SPSS vers. 22.0.0.0 (SPSS, Chicago, IL, USA) for Windows statistical software was used to conduct all data analyses. A p value of < 0.05 was deemed statistically significant.

Results

Characteristics of study subjects

The demographic characteristics and sleep parameters of the 1584 participants enrolled in the study are described in Table 1. Overall, study subjects had an average age of 47.2 ± (standard deviation (SD)) 14.3 years, and 62.3% of participants were men. We found that the pre-sleep total fat mass in both groups was insignificantly different. We observed that the neck circumference, waist circumference (WC), WASO, snoring index, AHI, AHI in the NREM sleep stage, AHI in the REM stage, apnea index (AI), hypopnea index (HI), AI/HI, N1%, supine AHI, and non-supine AHI were lower in the positional OSA patients than in non-positional OSA patients (all $p < 0.05$). However, in positional OSA patients, the TST, sleep efficiency, N2%, REM%, mean SaO_2, and time spent in the supine position were higher than those of non-positional OSA patients (all $p < 0.05$).

Overnight changes in body composition of OSA patients

As depicted in Table 2 and Table S1, we observed increases in the total fat percentage and visceral fat level (both $p < 0.05$). We observed declines in the body weight, muscle mass, fat-free mass, bone mass, extracellular water, intracellular water, and total body water (all $p < 0.05$). We also found an increase in the metabolic age and a decrease in the basal metabolic rate ($p < 0.05$). In lower limbs, we observed decreases in the fat mass, muscle mass, and fat-free mass and increases in the fat percent and impedance (all $p < 0.05$). In upper limbs, we observed decreases in the fat mass, fat percentage, muscle mass, and fat-free mass and an increase in the impedance (all $p < 0.05$). In the trunk, we observed increases in the fat percentage, fat mass, muscle mass, fat-free mass, and impedance (all $p < 0.05$).

Associations of sleep-related parameters with positional OSA

We observed that increases in the TST, sleep efficiency, N2%, REM%, and mean SaO_2 were preferentially associated with positional OSA than with non-positional OSA (all $p < 0.05$) (Table 3). We also found that increases in the neck circumference, WC, WASO, snoring index, AHI, AHI in the NREM sleep stage, AHI in the REM sleep stage, and N1% were less associated with positional OSA than with non-positional OSA (all $p < 0.05$).

Associations of body composition changes with positional OSA

Using patients with non-positional OSA as the reference group, we observed that increases in the pre-sleep fat percentage, fat percentage in lower limbs, fat percentage in upper limbs, trunk fat percentage, trunk fat mass, and trunk impedance were associated with increased ORs of positional OSA (all $p < 0.05$) (Table 4 and Table S2). We observed that associations of post-sleep body composition with positional OSA were insignificant.

We found that a 1-unit increase in overnight changes of the total fat percentage and total fat mass were associated with 1.076-fold increased OR (95% confidence interval (CI): 1.014, 1.142) and 1.096-fold increased OR (95% CI: 1.010, 1.189) of positional OSA, respectively (all $p < 0.05$). Also, a 1-unit increase in overnight changes of lower limb fat percentage and upper limb fat mass were associated with 1.043-fold increased OR (95% CI: 1.004, 1.084) and 2.638-fold increased OR (95% CI: 1.313,

Table 1 Demographics and sleep-related parameters of total subjects, and subjects with positional obstructive sleep apnea (OSA) and non-positional OSA (reference group)

Characteristic	Total subjects ($N=1584$) Mean ± SD	Positional OSA ($N=528$) Mean ± SD	Non-positional OSA ($N=1056$) Mean ± SD	p value*
Age, years	47.2 ± 14.2	46.7 ± 14.1	47.5 ± 14.2	0.302
Male, % (n) [a]	62.3 (987)	61.7 (326)	62.6 (661)	0.741
Body mass index, kg/m^2	26.1 ± 4.7	25.8 ± 4.4	26.2 ± 4.8	0.086
Neck circumference, cm	38.7 ± 7.6	37.6 ± 7.1	39.2 ± 7.8	< 0.001
Waist circumference, cm	93.4 ± 12.7	90.9 ± 10.5	94.7 ± 13.5	< 0.001
Pre-sleep total fat mass, kg	20.7 ± 9.4	20.4 ± 9.0	20.9 ± 9.7	0.387
Total sleep time, h	4.6 ± 0.9	4.7 ± 0.8	4.6 ± 0.9	0.004
Sleep efficiency, %	75.5 ± 14.7	76.8 ± 13.6	74.8 ± 15.2	0.009
WASO, min	64,0 ± 45.6	59.1 ± 40.7	66.4 ± 47.7	0.002
Snoring index, events/h	213.0 ± 222.7	184.3 ± 209.2	227.3 ± 227.8	< 0.001
AHI, events/h	34.1 ± 24.7	24.9 ± 16.2	38.7 ± 26.8	< 0.001
AHI in NREM, events/h	32.8 ± 25.82	23.5 ± 17.1	37.5 ± 28.1	< 0.001
AHI in REM, events/h	39.7 ± 26.6	32.0 ± 23.3	43.5 ± 27.3	< 0.001
AI, events/h	9.4 ± 15.6	6.5 ± 10.0	10.8 ± 17.6	< 0.001
HI, events/h	24.7 ± 17.9	18.4 ± 11.7	27.9 ± 19.5	< 0.001
AI/HI	0.72	0.46	0.86	0.035
Sleep cycle of total sleep time				
N1, %	19.1 ± 13.5	16.0 ± 10.5	20.6 ± 14.6	< 0.001
N2, %	62.6 ± 13.7	65.0 ± 12.4	61.4 ± 14.2	< 0.001
N3, %	4.9 ± 8.0	4.8 ± 7.7	5.0 ± 8.1	0.653
REM, %	13.4 ± 7.1	14.1 ± 7.1	13.0 ± 7.0	0.002
Arousal index in total, events/h	18.0 ± 12.3	17.4 ± 12.2	18.3 ± 12.4	0.191
Arousal index in NREM, events/h	17.7 ± 12.8	17.1 ± 12.6	17.9 ± 12.8	0.237
Arousal index in REM, events/h	18.8 ± 15.4	18.2 ± 14.8	19.2 ± 15.7	0.234
Mean SaO_2, %	94.7 ± 2.3	95.2 ± 1.6	94.5 ± 2.5	< 0.001
Time spent in supine position, min	156.4 ± 75.3	166.1 ± 75.1	151.6 ± 74.9	< 0.001
Supine AHI, events/h	43.1 ± 28.2	38.8 ± 23.2	45.2 ± 30.2	< 0.001
Non-supine AHI, events/h	46.29 ± 58.0	10.2 ± 9.2	64.3 ± 63.5	< 0.001

*The comparison analysis between positional OSA and non-positional OSA data was based on independent samples t test. $p < 0.05$ is deemed to be statistically significant

[a]Chi-squared test

Definitions of abbreviations: *AI*, apnea index; *HI*, hypopnea index; *AHI*, apnea–hypopnea index; *N1%*, percentage of the total sleep time (TST) in the non-rapid eye movement (NREM) sleep stage I; *N2%*, percentage of the TST in NREM sleep stage II; *N3%*, percentage of the TST in NREM sleep stage III; *REM%*, percentage of the TST in the rapid eye movement sleep stage; *SaO_2*, arterial oxygen saturation measured by pulse oximetry; *SD*, standard deviation; *WASO*, wake time after sleep onset

5.302) of positional OSA, respectively (all $p < 0.05$). We observed that a 1-unit increase in overnight changes of trunk fat percentage and trunk fat mass were associated with 1.056-fold increased OR (95% CI: 1.008, 1.106) and 1.150-fold increased OR (95% CI: 1.016, 1.301) of positional OSA, respectively (all $p < 0.05$).

Furthermore, we found that changes in the muscle mass, the fat-free mass, the total body water, extracellular water, intracellular water, the basal metabolic rate, and the physique rating were associated with decreased ORs of positional OSA (all $p < 0.05$).

Discussion

Our study shed light on the understanding of the pathogenesis of positional OSA. Results showed that the pre-sleep total fat percentage and segmental fat percentage were associated with positional OSA. We observed that an increase in changes of the total fat percentage, total fat mass, lower limb fat percentage, upper limb fat mass, trunk fat percentage, and trunk fat mass were associated with an increased odds ratio of positional OSA compared with non-positional OSA.

Table 2 Pre-sleep, post-sleep, and changes in body composition parameters of total subjects ($N = 1584$)

	Pre-sleep Mean ± SD	Post-sleep Mean ± SD	Change Mean ± SD	*p* value*
Weight, kg	72.03 ± 15.56	71.29 ± 15.45	0.74 ± 0.50	< 0.001
Fat percent, %	28.2 ± 8.9	28.6 ± 8.5	− 0.4 ± 1.9	< 0.001
Fat mass, kg	20.73 ± 9.43	20.78 ± 9.05	− 0.05 ± 1.40	0.150
Muscle mass, kg	48.55 ± 10.28	47.80 ± 10.11	0.75 ± 1.31	< 0.001
Visceral fat level, kg	10.91 ± 4.80	10.98 ± 4.81	− 0.08 ± 0.57	< 0.001
Bone mass, kg	2.76 ± 0.49	2.71 ± 0.49	0.05 ± 0.09	< 0.001
Fat-free mass, kg	51.31 ± 10.75	50.51 ± 10.57	0.79 ± 1.39	< 0.001
Body water				
TBW, kg	35.79 ± 7.09	34.34 ± 6.54	1.46 ± 1.58	< 0.001
ECW, kg	14.75 ± 2.40	14.50 ± 2.31	0.24 ± 0.38	< 0.001
ICW, kg	21.05 ± 4.86	19.82 ± 4.41	1.23 ± 1.22	< 0.001
Metabolism				
BMR, kJ	6166.15 ± 1228.32	6068.47 ± 1211.38	97.67 ± 156.50	< 0.001
METAAGE, year	45.76 ± 13.37	46.45 ± 13.13	− 0.70 ± 3.14	< 0.001
Lower limbs				
FATP, %	54.4 ± 16.5	56.1 ± 15.6	− 1.7 ± 3.1	< 0.001
FATM, kg	7.28 ± 3.20	7.09 ± 2.85	0.19 ± 0.60	< 0.001
FFM, kg	19.28 ± 4.98	18.14 ± 4.74	1.14 ± 0.60	< 0.001
PMM, kg	18.20 ± 4.72	17.13 ± 4.49	1.07 ± 0.60	< 0.001
IMP, Ω	462.46 ± 71.87	514.67 ± 78.99	− 52.21 ± 24.56	< 0.001
Upper limbs				
FATP, %	47.8 ± 19.3	46.7 ± 190	1.1 ± 3.8	< 0.001
FATM, kg	1.66 ± 0.99	1.57 ± 0.95	0.09 ± 0.16	< 0.001
FFM, kg	5.13 ± 1.29	4.99 ± 1.23	0.14 ± 0.24	< 0.001
PMM, kg	4.80 ± 1.20	4.66 ± 1.15	0.13 ± 0.24	< 0.001
IMP, Ω	656.70 ± 118.83	673.54 ± 117.22	− 16.84 ± 35.30	< 0.001
Trunk				
FATP, %	29.6 ± 9.6	29.8 ± 9.1	− 0.2 ± 2.4	0.001
FATM, kg	11.79 ± 5.45	12.12 ± 5.47	− 0.33 ± 0.88	< 0.001
FFM, kg	26.90 ± 4.98	27.38 ± 4.99	− 0.48 ± 1.24	< 0.001
PMM, kg	25.55 ± 4.82	26.01 ± 4.83	− 0.46 ± 1.17	< 0.001
IMP, Ω	593.29 ± 93.60	630.67 ± 97.57	− 37.38 ± 24.86	< 0.001
Phase angle, φ	6.01 ± 0.96	6.13 ± 0.91	− 0.12 ± 0.83	< 0.001
Physique rating	30.67 ± 10.24	29.57 ± 9.64	1.11 ± 4.70	< 0.001

*The comparison analysis between pre-sleep and post-sleep data was based on Student's paired samples *t* test. $p < 0.05$ is deemed to be statistically significant

Definitions of abbreviations: *TBW*, total body water; *ECW*, extracellular water; *ICW*, intracellular water; *BMR*, basal metabolic rate; *METAAGE*, metabolic age; *FATP*, fat percent; *FATM*, fat mass; *FFM*, fat-free mass; *PMM*, predicted muscle mass; *IMP*, impedance; *SD*, standard deviation

Reductions in body weight and total body fluid in patients with OSA over a night's sleep were observed in this study, probably due to nighttime urination or excessive sweating [26, 27]. Previous studies also observed a reduction in body weight and total body water in patients with OSA [28]. Another study found that the body weight of patients with OSA reduced 0.3 ± 0.2 kg after one night's sleep due to fluid loss [29]. In brief, this suggests that OSA may be associated with changes in hormonal and sympathetic activities.

This is the first study to examine the effects of overnight body composition changes with positional OSA. We observed that increases in the TST, sleep efficiency, N2%, REM%, and mean SaO_2 were associated with higher ORs of positional OSA than those of non-positional OSA. Previous studies showed that sleep quality, sleep efficiency, and the percentage of deep sleep were higher in positional OSA than in non-positional OSA [2]. We also observed that increases in the AHI, AHI in the NREM sleep stage, and AHI in the REM sleep stage were associated with decreased ORs of

Table 3 Associations (odds ratio (OR)) of the positional obstructive sleep apnea (OSA) group ($N=528$) with the non-positional OSA group (reference) ($N=1056$) by sleep-related parameters (* $p<0.05$)

Sleep-related parameters	Adjusted OR (95% CI)	*p* value
Neck circumference, cm	0.947 (0.923, 0.972)*	< 0.001
Waist circumference, cm	0.976 (0.967, 0.984)*	< 0.001
Total sleep time, h	1.178 (1.046, 1.327)*	0.007
Sleep efficiency, %	1.009 (1.002, 1.017)*	0.014
WASO, min	0.996 (0.994, 0.999)*	0.003
Snoring index	0.999 (0.999, 0.999)*	0.002
AHI, events/h	0.972 (0.966, 0.977)*	< 0.001
AHI in NREM, events/h	0.974 (0.969, 0.979)*	< 0.001
AHI in REM, events/h	0.982 (0.978, 0.987)*	< 0.001
Sleep cycle of total sleep time		
N1, %	0.971 (0.962, 0.980)*	< 0.001
N2, %	1.021 (1.013, 1.029)*	< 0.001
N3, %	0.997 (0.984, 1.010)	0.666
REM, %	1.024 (1.009, 1.039)*	0.002
Arousals index in total, events/h	0.996 (0.987, 1.005)	0.427
Arousals index in NREM, events/h	0.997 (0.988, 1.006)	0.504
Arousals index in REM, events/h	0.997 (0.990, 1.004)	0.408
Mean SaO_2, %	1.151 (1.091, 1.215)*	< 0.001

Results were adjusted for age, sex, and body mass index. $p < 0.05$ is deemed to be statistically significant

Definitions of abbreviations: *AHI*, apnea–hypopnea index; *CI*, confidence interval; *N1%*, percentage of total sleep time (TST) in non-rapid eye movement (NREM) sleep stage I; *N2%*, percentage of TST in NREM sleep stage II; *N3%*, percentage of TST in NREM sleep stage III; *REM%*, percentage of TST in the rapid eye movement sleep stage; *SaO_2*, arterial oxygen saturation measured by pulse oximetry; *WASO*, wake time after sleep onset

positional OSA compared to those of non-positional OSA. Our findings implied that an increase in the AHI was associated with a higher odds ratio of non-positional OSA than with positional OSA. It was reported that positional OSA was associated with a mild or moderate degree of OSA while non-positional OSA was associated with higher severity of OSA [4]. Our findings suggest that positional OSA may be associated with better sleep efficiency and a higher percentage of deep sleep than is non-positional OSA.

We found that changes in the total fat distribution and segmental fat distribution were associated with higher ORs of positional OSA than those of non-positional OSA. Our previous study showed that nocturnal changes in the total fat distribution and leg fat distribution were associated with the severity of OSA [13]. Previous studies using a bioelectrical impedance analysis reported that changing the body position from a standing to a supine position resulted in a body fat redistribution [30, 31]. Furthermore, the accumulation of fat in the pharyngeal tissues during supine sleep may decrease the pharyngeal lumen size and upper airway muscle activity, thus facilitating OSA [32, 33]. Due to gravity, the supine position is associated with a decrease in the cross-sectional area of the upper airway, which may also facilitate OSA [34, 35]. Our findings suggest that changes in total fat percentage and total fat mass could be preferentially associated with positional OSA than non-positional OSA. Changes in lower limb fat percentage and upper limb fat mass may be preferentially associated with positional OSA than non-positional OSA.

Additionally, we observed that increased changes in muscle mass, fat-free mass, total body water, basal metabolic rate, and physique rating were associated with decreased ORs of positional OSA compared with non-positional OSA. Previous studies reported that overnight changes in fat-free mass, muscle mass, extracellular water, and basal metabolic rate were inversely associated with OSA severity [13]. Changing the body position could be associated with intracellular water, extracellular water, total body water, fat-free mass, and impedance shifts [31]. Previous studies also found that muscle mass and fat-free mass were inversely associated with the severity of OSA, suggesting a role of muscle depletion in upper airway collapsibility [11, 12]. Our results indicate that the body fluid, muscle mass, and fat-free mass redistribution could be associated with non-positional OSA.

We observed that the pre-sleep segmental fat percentage and fat mass were associated with increased ORs of positional OSA. It was reported that increases in the abdominal fat and parapharyngeal fat distributions could result in increased OSA severity [32, 36]. Our findings imply that the pre-sleep total and segmental fat distribution may be preferentially associated with positional OSA than non-positional OSA. Positional OSA might benefit from positional therapy and may be associated with less severe OSA compared with non-positional OSA [37–39]. Our findings implied that pre-sleep segmental fat distribution may be used to predict positional OSA. Furthermore, treatment to reduce the overnight changes in the fat distribution may benefit the patients with positional OSA.

The problem of multiple comparisons occurs when testing multiple hypotheses simultaneously [40–42]. This problem can raise the probability of committing false-positive statistical inferences. The increased risk of family-wise type 1 error resulting from multiple comparisons could be controlled by various methods (i.e., Tukey method, Dunnett method, Bonferroni correction, and controlling false discovery rate) [40, 42, 43]. In this study, we aimed to investigate the associations between overnight changes in the body composition and positional OSA using the non-position OSA as the reference group after adjusting for age, sex, and BMI. We examined the odds ratios of outcome variables between positional OSA group (case) and non-positional OSA group (reference) using the logistic regression analysis. Since we

Table 4 Associations (odds ratio (OR)) of the positional obstructive sleep apnea (OSA) group ($N=528$) with the non-positional OSA group (reference) ($N=1056$) by pre-sleep, post-sleep, and overnight changes in body composition (* $p<0.05$)

	Pre-sleep body composition	*p* value	Post-sleep body composition	*p* value	Changes in body composition	*p* value
Weight, kg	1.003 (0.983, 1.023)	0.802	1.003 (0.983, 1.023)	0.801	1.000 (0.804, 1.244)	0.998
Fat percent, %	1.047 (1.013, 1.082)*	0.007	1.027 (0.991, 1.064)	0.148	1.076 (1.014, 1.142)*	0.015
Fat mass, kg	1.031 (0.995, 1.067)	0.089	1.014 (0.978, 1.052)	0.454	1.096 (1.010, 1.189)*	0.028
Muscle mass, kg	0.989 (0.965, 1.014)	0.392	0.998 (0.972, 1.024)	0.851	0.905 (0.829, 0.987)*	0.024
Visceral fat level, kg	1.081 (0.986, 1.185)	0.098	1.054 (0.960, 1.157)	0.272	1.121 (0.929, 1.352)	0.234
Bone mass, kg	0.869 (0.578, 1.307)	0.501	0.959 (0.626, 1.469)	0.846	0.425 (0.129, 1.400)	0.159
Fat-free mass, kg	0.990 (0.967, 1.013)	0.396	0.998 (0.973, 1.022)	0.850	0.911 (0.840, 0.989)*	0.027
Body water						
TBW, kg	0.976 (0.949, 1.005)	0.105	0.988 (0.958, 1.019)	0.447	0.916 (0.851, 0.986)*	0.020
ECW, kg	0.939 (0.839, 1.051)	0.276	0.994 (0.882, 1.121)	0.928	0.688 (0.510, 0.929)*	0.015
ICW, kg	0.965 (0.929, 1.002)	0.066	0.978 (0.938, 1.019)	0.287	0.908 (0.826, 0.999)*	0.047
Metabolism						
BMR, kJ	1.000 (0.999, 1.000)	0.397	1.000 (0.999, 1.000)	0.809	0.999 (0.998, 0.999)*	0.032
METAAGE, year	1.014 (0.998, 1.030)	0.089	1.007 (0.991, 1.024)	0.401	1.034 (0.997, 1.071)	0.069
Lower limbs						
FATP, %	1.024 (1.002, 1.047)*	0.036	1.012 (0.988, 1.037)	0.332	1.043 (1.004, 1.084)*	0.031
FATM, kg	1.003 (0.911, 1.105)	0.944	0.969 (0.868, 1.081)	0.573	1.152 (0.927, 1.433)	0.201
FFM, kg	0.970 (0.920, 1.023)	0.260	0.977 (0.921, 1.035)	0.427	0.865 (0.715, 1.048)	0.138
PMM, kg	0.968 (0.916, 1.024)	0.259	0.975 (0.916, 1.037)	0.418	0.863 (0.706, 1.056)	0.153
IMP, Ω	1.002 (0.999, 1.004)	0.065	1.002 (0.999, 1.004)	0.129	1.001 (0.997, 1.006)	0.594
Upper limbs						
FATP, %	1.021 (1.004, 1.038)*	0.013	1.014 (0.996, 1.032)	0.123	1.027 (0.998, 1.058)	0.068
FATM, kg	1.234 (0.952, 1.598)	0.112	1.075 (0.820, 1.409)	0.601	2.638 (1.313, 5.302)*	0.006
FFM, kg	0.907 (0.752, 1.094)	0.309	0.940 (0.775, 1.140)	0.530	0.800 (0.511, 1.252)	0.329
PMM, kg	0.896 (0.739, 1.087)	0.265	0.929 (0.761, 1.133)	0.467	0.797 (0.505, 1.258)	0.330
IMP, Ω	1.002 (0.999, 1.003)	0.070	1.001 (0.999, 1.003)	0.104	1.000 (0.997, 1.003)	0.818
Trunk						
FATP, %	1.035 (1.008, 1.062)*	0.009	1.021 (0.992, 1.050)	0.157	1.056 (1.008, 1.106)*	0.022
FATM, kg	1.061 (1.006, 1.118)*	0.028	1.036 (0.981, 1.093)	0.203	1.150 (1.016, 1.301)*	0.027
FFM, kg	0.993 (0.954, 1.033)	0.714	1.008 (0.967, 1.051)	0.702	0.928 (0.848, 1.016)	0.107
PMM, kg	0.992 (0.951, 1.035)	0.725	1.010 (0.966, 1.056)	0.670	0.921 (0.836, 1.015)	0.096
IMP, Ω	1.002 (1.000, 1.004)*	0.036	1.002 (0.999, 1.003)	0.114	1.002 (0.997, 1.006)	0.420
Phase angle, φ	0.938 (0.823, 1.069)	0.339	1.001 (0.870, 1.151)	0.992	0.938 (0.824, 1.067)	0.330
Physique rating	0.975 (0.960, 0.991)*	0.002	0.984 (0.969, 1.001)	0.058	0.976 (0.954, 0.999)*	0.040

Results were adjusted for age, sex, and body mass index. $p < 0.05$ is deemed to be statistically significant

Definitions of abbreviations: *TBW*, total body water; *ECW*, extracellular water; *ICW*, intracellular water; *BMR*, basal metabolic rate; *METAAGE*, metabolic age; *FATP*, fat percent; *FATM*, fat mass; FFM, fat-free mass; *PMM*, predicted muscle mass; *IMP*, impedance

compared the outcomes between two groups, we did not use multiple comparisons and post-hoc analysis in this study. We will take into consideration the multiple comparisons in our future work.

There are limitations to our study. Because our study design was cross-sectional, causal relationships cannot be inferred. Also, some risk factors associated with sleep parameters and body composition should be included in future work (i.e., alcohol consumption, smoking, diet, food and fluid intake, and physical activity).

Conclusions

This is the first study to investigate associations of body composition with positional OSA. We found that changes in the total fat percentage, total fat mass, lower limb fat percentage, upper limb fat mass, trunk fat percentage, and trunk fat mass were associated with increased odds ratios of positional OSA. Our findings suggest that these overnight changes in the fat percentage and fat mass were

preferentially associated with positional OSA compared with non-positional OSA.

Glossary

Basal metabolic rate, the minimum level of energy the body needs at rest to function effectively.

Body fat mass, the weight of fat in the body.

Body fat percentage, the amount of body fat as a proportion of total body weight.

Bone mass, the amount of bone in the body.

Fat-free mass, all body components except fat.

Metabolic age, calculated by comparing one's basal metabolic rate to the average of one's chronological age group.

Muscle mass, the weight of muscle in the body.

Peripheral fat percentage, the amount of peripheral fat as a proportion of the total peripheral weight.

Physique rating, the ratio of body fat and muscle mass in the body.

Total body water, the total amount of fluid in the body.

Visceral fat, fat in the abdominal cavity, surrounding the vital organs in the trunk.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11325-022-02664-5.

Acknowledgements The authors heartedly thank all of the staff at the Sleep Center of Shuang Ho Hospital for technical assistance during this project. This study was funded by the Ministry of Science and Technology of Taiwan (MOST 109-2314-B-038-093-MY3).

Author contribution HCC and NTT contributed to interpretation of the data and completion of the manuscript. HCC and WTL contributed substantially to the concept, design, interpretation of the data, and completion of the study and manuscript. CYT, SYL, CCL, KL, and YCK contributed to sample collection and data analyses. HBD and TPCT contributed to critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript.

Funding This study was funded by the Ministry of Science and Technology of Taiwan (MOST 109–2314-B-038–093-MY3).

Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval The study protocol (TMU-JIRB no. N201912095) was approved by the Taipei Medical University (Taipei, Taiwan) joint institutional review board (JIRB).

Competing interests The authors declare no competing interests.

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