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Menopause and obstructive sleep apnea: revealing an independent mediating role of visceral fat beyond body mass index

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Abstract

Background Menopause is a significant phase in women's health, in which the incidence of obstructive sleep apnea (OSA) is significantly increased. Body fat distribution changes with age and hormone levels in postmenopausal women, but the extent to which changes in body fat distribution affect the occurrence of OSA is unclear.

Methods This research performed a cross-sectional analysis utilizing data from the 2015–2016 National Health and Nutrition Examination Survey (NHANES). Body fat distribution was quantified using dual-energy X-ray absorptiometry in kilograms. Menopausal status and OSA symptoms were determined by questionnaire. Weighted multivariable regression analysis was utilized to investigate the correlation between menopausal status and OSA symptoms and body fat composition. We did a mediation analysis to assess how much of the effect of menopausal status on OSA symptoms was mediated through in body fat composition.

Results The analysis comprised 1459 individuals from NHANES, consisting of 1188 premenopausal and 271 postmenopausal women. In the weighted sample, 36.01% of premenopausal women and 53.39% of postmenopausal women had OSA symptoms. After adjusting for body mass index (BMI) and other potential confounders, menopausal status was correlated with a higher prevalence of OSA symptoms (OR = 1.57; 95% CI: 1.16,2.13), and increased visceral fat mass (β = 0.12; 95% CI: 0.07, 0.17). In addition, visceral fat mass exhibited a significant correlation with OSA symptoms (OR = 3.79; 95% CI: 1.61, 8.94). Mediation analysis showed that 29.76% of the effect of menopausal status on OSA symptoms was mediated through visceral fat. In age-matched analysis, postmenopausal women had higher visceral fat mass (0.63 kg vs. 0.52 kg, $P = 0.02$) and a higher prevalence of OSA symptoms (68.3% vs. 45.7%, $P = 0.02$) compared with premenopausal women; however, there was no significant difference in BMI ($P > 0.05$).

Conclusion Our results suggest that menopausal status is associated with increased visceral fat accumulation and OSA symptoms prevalence. Visceral fat accumulation appears to play an important role in the development of OSA in postmenopausal women, independent of BMI; this highlights the importance of further studying this relationship.

Keywords Obstructive sleep apnea, Menopause, Obesity, Visceral fat, NHANES

Introduction

The average life expectancy for women worldwide is approximately 76 years, according to the World Health Organization [1]. Most women experience menopausal transition between the ages of 45 and 55. As life expectancy increases, women can anticipate spending half of

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their lives in menopause [2]. This transition is a critical time in women's health [3]. Inevitable aging, declining estrogen and progesterone levels, and changes in body fat distribution may elevate the risk of sleep apnea [4].

Obstructive sleep apnea (OSA) is a common form of sleep-disordered breathing [5]. Traditionally, aging, male gender, and obesity were considered substantial risk factors for OSA [6]. While males have a higher prevalence of OSA than females, this gender discrepancy diminishes with advancing age. The prevalence of OSA in postmenopausal women increases significantly, the severity is equivalent to that in males, and the gender difference is no longer obvious [6–8]. However, the clinical presentation of OSA in middle-aged women are often less typical and therefore easily overlooked [9].

Although the precise mechanism of heightened occurrence of OSA in postmenopausal women is not yet completely comprehended, it may be associated with alterations in body fat distribution [10, 11]. In this study, we used the National Health and Nutrition Examination Survey (NHANES) 2015–2016 database to evaluate the correlation between menopausal state and OSA symptoms in women and analyze the potential mediating effect of body fat distribution on this relationship.

Method

Study population and research design

The research population was sourced from the NHANES 2015–2016 database, a survey that is nationally representative and conducted by the National Center for Health Statistics (NCHS). NHANES is an important initiative of the NCHS aimed at evaluating the health and nutritional status of American adults and children. Each NHANES cycle includes a questionnaire survey and standardized health check-ups, as well as physical and laboratory tests using mobile testing equipment. From 2015 to 2016, a total of 9971 individuals participated in the research, and 3041 of them answered two questions about the definition of menopause in the reproductive questionnaire. The final analysis included 1459 participants after excluding female participants who used hormone replacement therapy (n = 383), participants with absent OSA symptoms definitions (n = 508), and participants without Dual-energy X-ray absorptiometry (DXA) measurement data (n = 691). Figure 1 shows the inclusion and excluding procedure.

Menopausal status

Self-reported menopausal status has been shown to be highly accurate [12]. Based on previous literature, we used two questions from the NHANES Reproductive Health Questionnaire to assess menopausal status:

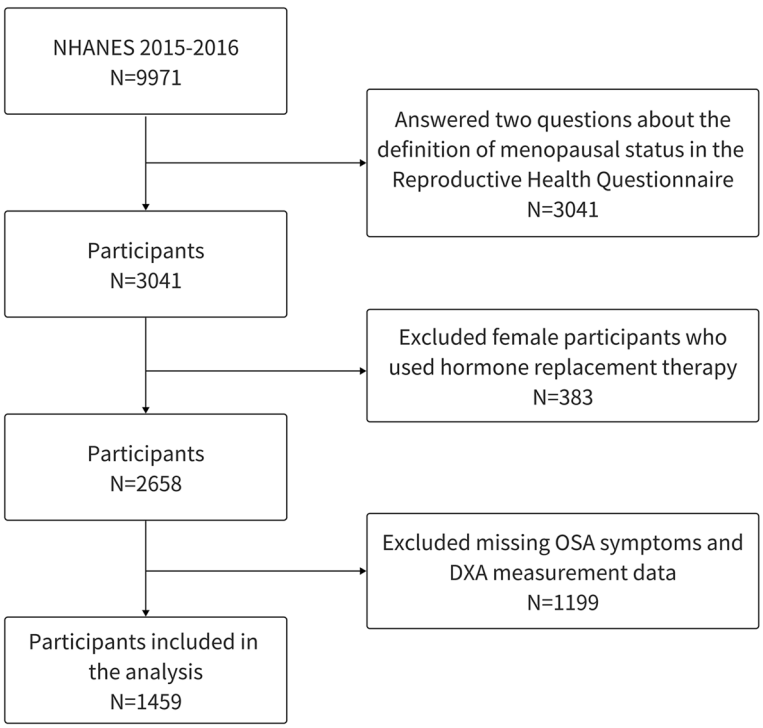

Fig. 1 Flowchart of participants inclusion and exclusion from NHANES 2015–2016

(1) Had regular periods in past 12 months; (2) Reason not having regular periods. Participants were classified as postmenopausal if they responded “No” to the first question and indicated "Hysterectomy/Menopause or Change of life" to the second question. Participants were classified as premenopausal if they answered “Yes” to the first question, or if they answered "No" to the first question and “Pregnancy”, “Breast feeding”, or “Other” to the second question, provided they were under 55 years of age [13]. We classified women who reported having undergone bilateral oophorectomy as postmenopausal because such surgery can lead to premature ovarian failure, resulting in a dramatic drop in ovarian sex hormone levels [14]. Compared to the general population, premenopausal ovariectomy is associated with more pronounced and longer-lasting menopausal symptoms [15]. Furthermore, we excluded women who had ever received hormone replacement therapy, such as estrogen and progesterone, due to concerns about its potential effects on body fat distribution [16, 17]. The assessment of female hormone use was conducted through the question, “Ever use female hormones?” We also performed a sensitivity analysis to exclude women who had undergone hysterectomy with uncertain menopausal status (Supplementary material).

OSA Symptoms

OSA symptoms were diagnosed according to the Sleep Disorder Questionnaire: (1) How often do you snore? (2) How often do you snort or stop breathing? or (3) felt almost always overly sleepy per month despite usually sleeping 7 or more hours on weekdays or workdays. The criteria for defining OSA symptoms were based on prior research and included answering “occasionally” or “often” to one of the first two questions, or “yes” to the third question [18].

Body fat mass assessment

A DXA whole body scan was conducted on eligible participants aged 8 to 59 years to assess body composition. DXA is the most commonly established tool for determining body composition. The NHANES Mobile Examination Center’s certified radiologic technologists performed the scans. The whole body scans were acquired on the Hologic Discovery model A densitometers (Hologic, Inc., Bedford, Massachusetts), using software version Apex 3.2. Exclusion criteria for these scans included pregnancy, recent use of radiographic contrast materials (barium), or a bodyweight exceeding 450 pounds. This analysis includes total abdominal fat, visceral fat, subcutaneous fat, android fat, and gynoid fat mass. All measurements are converted to kilogram (kg).

Covariates

Baseline demographics, medical comorbidities, and lifestyle factors were investigated, including age, self-reported sex (male and female), self-reported race, body mass index (BMI), waist circumference, smoking, alcohol, hypertension, diabetes, physical activity, estradiol, testosterone, and total cholesterol levels. Smoking was characterized as the smoking of a minimum of 100 cigarettes over a lifetime, while drinking was defined as the intake of at least 12 alcoholic beverages annually. Hypertension and diabetes were determined by self-report. Although self-reported hypertension and diabetes are not equivalent to formal diagnoses, they have been shown to be screening measures for hypertension and diabetes in epidemiological studies [19–21]. Physical activity was defined by a questionnaire inquiring if individuals engaged in vigorous-intensity activities for at least 10 min continuously each week. In addition, potentially relevant laboratory test results are included. The NHANES Laboratory Procedure Manual offers detailed instructions for collecting and processing specimens.

Statistical analyses

All analyses except Tables 5 and 6 and Supplementary Table 4 used sampling weights to account for the complex sampling design of NHANES. The sampling weight was calculated as follows: full sample 2-year MEC exam weight. Weighted baseline characteristics were categorized according to menopausal status. Continuous variables were presented as mean (SE), and categorical variables as percentage (95% CI). Weighted multivariable logistic regression analysis and reported ORs were used to assess the relationship between both menopausal status and body fat distribution and OSA symptoms. Weighted multivariable linear regression analysis was used to investigate the relationship between menopausal status and body fat distribution. Two models were used: unadjusted and adjusted for potential confounders based on previous literature. In addition, we did mediation analysis using the product of coefficients method, and calculating the indirect effect of menopausal status on OSA symptoms mediated through body fat distribution compared with the total effect of menopausal status on OSA symptoms. Considering the differences in baseline age between the two groups of participants (Table 1), 4:1 propensity score matching (PSM) analysis was performed to adjust for age differences in this study [22]. After the matching process, the two groups were compared according to baseline characteristics to reassess the comparability of the two groups. Statistical analysis was performed using R version 4.3.3 (nhanesR package).

Table 1 Baseline characteristics of premenopausal and postmenopausal women

Baseline	Premenopausal women ($N=1188$)	Postmenopausal women ($N=271$)	*P*-value
	Mean (SE)	**Mean (SE)**	
Age (years)	32.42(0.40)	52.77(0.45)	**<0.01**
BMI (kg/m^2)	28.94(0.32)	29.72(0.87)	0.33
Waist circumference (cm)	94.39(0.77)	99.56(1.60)	**<0.01**
Total abdominal fat (kg)	2.31(0.04)	2.62(0.11)	**0.01**
Visceral fat (kg)	0.41(0.01)	0.62(0.03)	**<0.01**
Subcutaneous fat (kg)	1.90(0.04)	2.01(0.08)	0.18
Android fat (kg)	2.39(0.06)	2.76(0.14)	**0.01**
Gynoid fat (kg)	5.36(0.09)	5.51(0.17)	0.43
Testosterone (ng/dL)	26.47(1.32)	19.93(0.52)	**<0.01**
Estradiol (pg/mL)	96.57(2.17)	23.51(3.51)	**<0.01**
Total cholesterol (mmol/L)	4.59(0.04)	5.50(0.11)	**<0.01**
	Percentage (95% CI)	**Percentage (95% CI)**	
Race, n (%)			0.07
Mexican American	11.85(6.13,17.57)	7.61(2.07,13.16)	
Non-Hispanic Black	13.00(7.74,18.26)	13.74(8.23,19.26)	
Non-Hispanic White	57.51(48.08,66.94)	63.66(53.02,74.30)	
Other Hispanic	7.17(4.38, 9.96)	8.14(3.14,13.13)	
Other Race	10.47(8.06,12.88)	6.85(3.95, 9.75)	
OSA symptoms, n (%)	36.01(33.25,38.76)	53.39(42.88,63.90)	**<0.01**
Smoking, n (%)	27.27(22.23,32.30)	47.84(40.12,55.56)	**<0.01**
Alcohol, n (%)	64.62(59.91,69.33)	69.65(62.97,76.33)	**<0.01**
Hypertension, n (%)	12.25(9.85,14.65)	36.54(27.73,45.34)	**<0.01**
Diabetes, n (%)	3.69(2.58, 4.81)	9.67(6.00,13.34)	**<0.01**
Physical activity, n (%)	38.73(35.18,42.27)	22.56(14.79,30.33)	**<0.01**

Significant results are in bold

Continuous variables were presented as mean (SE), and categorical variables as percentage (95% CI).*Abbreviations*: *SE* Standard error, *BMI* Body mass index, *OSA* Obstructive sleep apnea

Statistical significance was determined by two-sided p values < 0.05.

Ethics approval and consent to participate

All participants granted written informed consent, and the NCHS Ethics Review Board sanctioned the NHANES study methods. The protocol number of the NCHS IRB/ERB for 2015–2016 was #2011–17. All methods of this study were performed in accordance with the principles outlined in the Declaration of Helsinki. No further institutional review board approval was required for this secondary analysis. Users can download the data free of charge for research and publication.

Results

Baseline characteristics of premenopausal and postmenopausal women are shown in Table 1. Among them, 36.01% of premenopausal women and 53.39% of postmenopausal women had OSA symptoms. Postmenopausal women had increased visceral fat mass (0.62 kg vs. 0.41 kg), android fat mass (2.76 kg vs. 2.39 kg), and increased waist circumference (99.56 cm vs. 94.39 cm) compared with premenopausal women ($P<0.05$). Nevertheless, there were no significant differences in subcutaneous fat and gynoid fat mass ($P>0.05$). Furthermore, postmenopausal women had lower estradiol and testosterone levels and a higher total cholesterol level ($P<0.05$). Postmenopausal women were more likely to have hypertension and diabetes, smoked and drank more, and exercised less ($P<0.05$).

Table 2 The associations between menopausal status and OSA symptoms

Variable	Non-adjusted OR (95% CI)	*P*-value	Adjusted OR (95% CI)	*P*-value
Menopausal status	2.04(1.32,3.13)	**<0.01**	1.57(1.16, 2.13)	**0.01**

Significant results are in bold

Adjusted for race, BMI, smoking, alcohol, hypertension, diabetes, physical activity, and total cholesterol

Abbreviations: *OR* Odds ratio, *95% CI* 95% confidence interval, *BMI* Body mass index, *OSA* Obstructive sleep apnea

Table 3 Comparison of body fat distribution between premenopausal and postmenopausal women

Variable	Premenopausal women Mean (SE)	Postmenopausal women Mean (SE)	Non-adjusted β (95% CI)	*P*-value	Adjusted β (95% CI)	*P*-value
Total abdominal fat (kg)	2.31(0.04)	2.62(0.11)	0.31(0.10,0.53)	**0.01**	0.15(0.06, 0.23)	**< 0.01**
Visceral fat (kg)	0.41(0.01)	0.62(0.03)	0.21(0.14,0.28)	**< 0.01**	0.12(0.07, 0.17)	**< 0.01**
Subcutaneous fat (kg)	1.90(0.04)	2.01(0.08)	0.10(-0.05,0.26)	0.18	0.03(-0.03, 0.08)	0.33
Android fat (kg)	2.39(0.06)	2.76(0.14)	0.37(0.11,0.64)	**0.01**	0.13(0.02, 0.24)	**0.02**
Gynoid fat (kg)	5.36(0.09)	5.51(0.17)	0.15(-0.24,0.53)	0.43	0.08(-0.15, 0.31)	0.48

Significant results are in bold

Adjusted for race, BMI, smoking, alcohol, hypertension, diabetes, physical activity, and total cholesterol

Abbreviations: *SE* Standard error, *β* effect size, *95% CI* 95% confidence interval, *BMI* Body mass index, *OSA* Obstructive sleep apnea

Table 4 The associations between body fat distribution and OSA symptoms

Variable	Non-adjusted OR (95% CI)	*P*-value	Adjusted OR (95% CI)	*P*-value
Total abdominal fat (kg)	1.97(1.54, 2.51)	**< 0.01**	1.24(0.84, 1.85)	0.26
Visceral fat (kg)	13.10(5.11, 33.57)	**< 0.01**	3.79(1.61, 8.94)	**< 0.01**
Subcutaneous fat (kg)	2.14(1.61, 2.83)	**< 0.01**	0.87(0.49, 1.54)	0.60
Android fat (kg)	1.66(1.38, 1.99)	**< 0.01**	1.14(0.91, 1.43)	0.23
Gynoid fat (kg)	1.31(1.17, 1.47)	**< 0.01**	0.88(0.73, 1.05)	0.15

Significant results are in bold

Adjusted for race, BMI, smoking, alcohol, hypertension, diabetes, physical activity, and total cholesterol

Abbreviations: *OR* Odds ratio, *95% CI* 95% confidence interval, *BMI* Body mass index, *OSA* Obstructive sleep apnea

The multivariable logistic regression between menopausal status and OSA symptoms is shown in Table 2. In the unadjusted model, the likelihood of OSA symptoms in postmenopausal women was double that of premenopausal women (OR = 2.04; 95% CI 1.32, 3.13). The adjusted model maintained this association (OR = 1.57; 95% CI 1.16, 2.13).

Table 3 compares body fat distribution in premenopausal and postmenopausal women. In the unadjusted model, menopausal status correlated with increased total abdominal fat (β = 0.31; 95% CI 0.10, 0.53), visceral fat (β = 0.21; 95% CI 0.14, 0.28), and android fat mass (β = 0.37; 95% CI 0.11, 0.64). In the adjusted model, the above associations still existed, with β values of 0.15, 0.12, and 0.13, respectively ($P < 0.05$). Menopausal status was not clinically relevant to subcutaneous or gynoid fat mass ($P > 0.05$).

The correlation between body fat distribution and OSA symptoms is shown in Table 4. In the unadjusted model, fat mass in different body regions (total abdominal fat, visceral fat, subcutaneous fat, android fat, and gynoid fat) exhibited a significant correlation with OSA symptoms ($P < 0.05$). In the adjusted model, only visceral fat mass and OSA symptoms were statistically significant (OR = 3.79; 95% CI 1.61, 8.94). Mediation analyzes showed that 29.76% of the observational association of menopausal status with OSA symptoms was mediated through visceral fat (Table 5).

Sensitivity analyzes excluding hysterectomized women with uncertain menopausal status confirmed that the direction of statistical significance remained unchanged (Supplementary material).

To exclude the effect of age and compare the associations only by menopausal status, we performed age-matched analyses in premenopausal and postmenopausal women. In Table 6, it is indicated that postmenopausal women had a somewhat elevated BMI (32.68 kg/m^2 vs.

Table 5 Mediation analysis of the association between menopause and the risk of OSA symptoms mediated by visceral fat mass

Exposure	Non-adjusted β (95% CI)	*P*-value	Adjusted β (95% CI)	*P*-value
Total effect	0.23(0.15, 0.28)	**< 0.01**	0.11(0.04, 0.18)	**< 0.01**
Direct effect	0.10(0.03, 0.16)	**0.01**	0.08(0.01, 0.15)	**0.02**
Mediation effect	0.13(0.08, 0.16)	**< 0.01**	0.03(0.00, 0.05)	**0.03**
PM, %	57.20	**< 0.01**	29.76	**0.03**

Significant results are in bold

Adjusted for race, BMI, smoking, alcohol, hypertension, diabetes, physical activity, and total cholesterol

Abbreviations: *β* Effect size, *95% CI* 95% confidence interval, *BMI* Body mass index, *OSA* Obstructive sleep apnea

Table 6 Age-matched analysis of premenopausal and postmenopausal women

Baseline	Premenopausal women (*N* = 164)	Postmenopausal women (*N* = 41)	*P*-value
	Mean (SD)	Mean (SD)	
Age (years)	40.51(8.08)	42.07(4.58)	0.24
BMI (kg/m^2)	31.48(8.12)	32.68(7.13)	0.39
Waist circumference (cm)	99.88(17.73)	104.27(16.93)	0.15
Total abdominal fat (kg)	2.65(1.04)	2.94(0.99)	0.11
Visceral fat (kg)	0.52(0.28)	0.63(0.27)	**0.02**
Subcutaneous fat (kg)	2.14(0.85)	2.31(0.79)	0.23
Android fat (kg)	2.80(1.52)	3.16(1.46)	0.18
Gynoid fat (kg)	5.76(2.14)	5.72(1.58)	0.92
	N (%)	N (%)	
OSA symptoms, n (%)	75(45.7)	28(68.3)	**0.02**

Significant results are in bold

Continuous variables were presented as mean (SD), and categorical variables as N (%)

Abbreviations: *SD* Standard deviation, *BMI* Body mass index, *OSA* Obstructive sleep apnea

31.48 kg/m^2) relative to premenopausal women; however, this difference lacked statistical significance. Simultaneously, postmenopausal women had a greater visceral fat mass (0.63 kg vs. 0.52 kg) and a higher incidence of OSA symptoms (68.3% vs. 45.7%) in comparison to premenopausal women ($P < 0.05$).

Discussion

Epidemiological studies indicate a notable increase in the prevalence of OSA among postmenopausal women, and the gender difference is no longer obvious [23, 24]. These phenomena might be linked to aging and changes in sex hormone level [25–27]. Compared with natural menopause, surgical menopause is associated with an increased risk of OSA [28]. This increased risk has been attributed to the dramatic decline in endogenous sex hormones after oophorectomy, in contrast to the continued hormonal activity of the ovaries for many years after natural menopause [29, 30]. However, although it is recognized that menopausal women are at increased risk for sleep-disordered breathing, the exact mechanisms of this disorder have not been thoroughly elucidated. Currently, several potential pathophysiological hypotheses are being intensively investigated and considered as possible explanatory factors.

While aging may not entirely account for the elevated incidence of OSA in menopausal women, some observational studies indicate that aging contributes to the onset of OSA post-menopause [31, 32]. Furthermore, the higher frequency of OSA in postmenopausal women might be connected to the loss of the protective effects of estrogen and progesterone on ventilatory drive and upper airway patency [33, 34]. Progesterone has a stimulating effect on respiratory control, whereas estrogen can upregulate progesterone receptors, so augmenting the respiratory stimulating action of progesterone [35]. At the same time, sex hormones may influence the function of upper airway dilator muscles, as indicated by the reduced activity of the genioglossus muscle post-menopause compared to pre-menopause [36, 37].

Previous studies frequently overlooked how aging and changes in estrogen levels can further affect body fat distribution in postmenopausal women. Age-mediated fat infiltration of the viscera is closely related to OSA [38]. Similarly, sex hormones also play a role in lipid metabolism, energy expenditure, and fat synthesis [39]. Animal studies have found that a decrease in estradiol may lead to an increase in visceral rather than overall fat mass [40]. Clinical observation studies have found that postmenopausal women have a larger fat mass compared to premenopausal women and have a higher propensity for weight gain. At the same time, the fat distribution of postmenopausal women is more concentrated, characterized by visceral fat accumulation [10, 41].

However, no research has investigated the correlation between specific body fat deposition and OSA in postmenopausal women. Prior research on the correlation between menopause and OSA either overlooked the influence of central obesity or only considered basic body anthropomorphic measures [25, 32, 42]. Our cross-sectional study showed that visceral fat and android fat increased in postmenopausal women, whereas fat distribution in the subcutaneous and gynoid regions did not change significantly. Association analysis showed that total abdominal, visceral, and android fat mass was increased in postmenopausal women relative to premenopausal women. However, only visceral fat mass was clinically significantly associated with OSA symptoms. Mediation analyzes further showed that visceral fat accumulation partially explained the association between menopausal status and OSA symptoms.

Accumulation of visceral fat is a notable risk factor for OSA and is strongly correlated with the severity of the apnea index [43]. Research indicates that visceral fat correlates more significantly with the severity of OSA than BMI [44]. Increased visceral fat may result in diaphragmatic elevation, reduced end-expiratory lung volume, decreased airway stretch at end-expiration, and decreased pharyngeal cross-sectional area [45]. The specific mechanism may involve that fat accumulation may contribute to upper airway collapse during inspiration by restricting diaphragmatic movement and may be deposited in upper airway soft tissues, leading to anatomical

stenosis [43, 44, 46]. In addition, menopause may increase the amount of fat in the upper body, thereby increasing neck circumference [47]. Our research indicated no significant variation in BMI before and after menopause, while visceral fat mass was significantly different. It is difficult to directly assess changes in body fat redistribution using BMI alone, suggesting that the impact of central obesity cannot be ignored even for postmenopausal women who do not exhibit considerable increases in BMI or weight.

It is worth noting that age is a significant factor in the relationship between menopausal status and OSA [48]. Age has also been associated with alterations in body fat distribution in postmenopausal women. Some studies indicate that menopause may cause a shift of adipose tissue from peripheral locations to central regions, independent of age [49]. However, a meta-analysis attributed alterations in body weight and body composition in postmenopausal women mainly to aging, rather than menopause itself [50]. Given the complex relationship between age, menopause, and fat distribution, we chose not to adjust for age in our analyses. This decision was based on uncertainty about whether menopause-related changes in body fat distribution are completely independent of age-related changes. Although age is a well-established confounder of OSA, the physiological and metabolic changes that accompany menopause (such as changes in fat distribution) are difficult to distinguish from changes associated with aging. Therefore, adjusting for age may mask the specific contribution of menopause to these changes.

To better understand these relationships, we performed analyzes using a small age-matched sample to control for age-related confounders. This approach revealed significant differences in visceral fat mass between postmenopausal and premenopausal women, with postmenopausal women having a higher prevalence of OSA symptoms. These findings highlight the independent role of menopause in the development of fat distribution and OSA and are not entirely attributable to the effects of age.

This study has several limitations. First, our definition of OSA symptoms was based on participants' responses to a sleep disturbance questionnaire rather than the results of polysomnography, which may not fully reflect the scope of sleep disorders. Considering that OSA symptoms in menopausal women may present as abnormal symptoms such as insomnia, fatigue, anxiety, or mood changes, these findings should be interpreted with caution [51]. Second, the cross-sectional design constrained our ability to determine a causal association between menopausal status and OSA symptoms. In addition, although we excluded participants who had ever received female hormone therapy, we were unable to implement additional, more detailed exclusions due to limitations of the NHANES questionnaire, which does not include an inquiry into current use of female hormone therapy. Also, the DXA inclusion criteria were limited to adult women aged 20–59 years, which may have narrowed the study scope and introduced selection bias. Despite adjustment for many confounding variables, potential confounders may still affect our results. Future prospective studies are needed to verify whether our conclusions from the NHANES database can be generalized to other populations and regions.

Despite these limitations, to our knowledge, our study is the inaugural investigation to use nationally representative data to investigate the correlation between alterations in body fat distribution and OSA symptoms in postmenopausal women. In contrast to premenopausal women, the redistribution of body fat in postmenopausal women, with visceral fat accumulation, correlates with an increased risk of OSA symptoms. As women experience increased longevity, menopause and sleep-disordered breathing will persist for an extended duration, thereby adversely affecting their quality of life. Sleep experts must recognize that changes in body fat distribution, independent of BMI, may significantly influence OSA in postmenopausal women; however, these changes are modest and often overlooked. For postmenopausal women, even if BMI has not increased significantly, it is necessary to be alert to the possibility of the accumulation of visceral fat. Considering that dietary modification and exercise training have shown successful in diminishing visceral fat, therapies focusing on food and exercise in postmenopausal women exhibiting OSA symptoms are valuable [52, 53].

Conclusion

Menopause as a turning point in women's health, with impacts beyond reproductive transition and closely related to metabolic disorders. Our results suggest that menopausal status is associated with increased visceral fat accumulation and OSA symptoms prevalence. Visceral fat accumulation has a significant impact on the occurrence and development of OSA in postmenopausal women, and is independent of BMI. This subtle alteration in body fat distribution underscores the need for further study of this relationship.

Abbreviations

NHANES	National Health and Nutrition Examination Survey
NCHS	National Center for Health Statistics
OSA	Obstructive sleep apnea
BMI	Body mass index
DXA	Dual-energy X-ray absorptiometry
HDL-C	High-density lipoprotein cholesterol
PSM	Propensity score matching

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12902-025-01850-2.

Supplementary Material 1.

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Clinical trial number
Not applicable.

Authors' contributions
Y.W. and H.L. wrote the main manuscript text and performed the statistical analysis. B.Z. and W.Y. performed data extraction and statistical analysis. M.W. reviewed and edited the manuscript. K.H. designed and supervised the study, revised and edited the manuscript. All authors have read and agreed to the published version of the manuscript.

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Data availability
Detailed NHANES study designs and data are available to the public at https://www.cdc.gov/nchs/nhanes/.

Declarations

Ethics approval and consent to participate
All participants gave written informed consent, and the NCHS Ethics Review Board approved the NHANES study methods. The NCHS IRB/ERB protocol number for NHANES 2015–2016 was #2011–17.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Life Expectancy by Country and in the World (2024) - Worldometer. Accessed May 13, 2024.https://www.worldometers.info/demographics/life-expectancy/.
2. Banks S. Menopause and the NHS: caring for and retaining the older workforce. Br J Nurs Mark Allen Publ. 2019;28(16):1086–90. https://doi.org/10.12968/bjon.2019.28.16.1086.
3. Endocrinology TLD&. Menopause: a turning point for women's health. Lancet Diabetes Endocrinol. 2022;10(6):373. https://doi.org/10.1016/S2213-8587(22)00142-5.
4. Perger E, Mattaliano P, Lombardi C. Menopause and sleep apnea. Maturitas. 2019;124:35–8. https://doi.org/10.1016/j.maturitas.2019.02.011.
5. Jordan AS, McSharry DG, Malhotra A. Adult obstructive sleep apnoea. Lancet Lond Engl. 2014;383(9918):736–47. https://doi.org/10.1016/S0140-6736(13)60734-5.
6. Lyons MM, Bhatt NY, Pack AI, Magalang UJ. Global burden of sleep-disordered breathing and its implications. Respirol Carlton Vic. 2020;25(7):690–702. https://doi.org/10.1111/resp.13838.
7. Young T, Peppard PE, Gottlieb DJ. Epidemiology of obstructive sleep apnea: a population health perspective. Am J Respir Crit Care Med. 2002;165(9):1217–39. https://doi.org/10.1164/rccm.2109080.
8. Tishler PV, Larkin EK, Schluchter MD, Redline S. Incidence of sleep-disordered breathing in an urban adult population: the relative importance of risk factors in the development of sleep-disordered breathing. JAMA. 2003;289(17):2230–7. https://doi.org/10.1001/jama.289.17.2230.
9. Bonsignore MR, Saaresranta T, Riha RL. Sex differences in obstructive sleep apnoea. Eur Respir Rev Off J Eur Respir Soc. 2019;28(154):190030. https://doi.org/10.1183/16000617.0030-2019.
10. Opoku AA, Abushama M, Konje JC. Obesity and menopause. Best Pract Res Clin Obstet Gynaecol. 2023;88:102348. https://doi.org/10.1016/j.bpobgyn.2023.102348.
11. Deng H, Duan X, Huang J, et al. Association of adiposity with risk of obstructive sleep apnea: a population-based study. BMC Public Health. 2023;23(1):1835. https://doi.org/10.1186/s12889-023-16695-4.
12. Colditz GA, Stampfer MJ, Willett WC, et al. Reproducibility and validity of self-reported menopausal status in a prospective cohort study. Am J Epidemiol. 1987;126(2):319–25. https://doi.org/10.1093/aje/126.2.319.
13. Azarmanesh D, Bertone-Johnson ER, Pearlman J, Liu Z, Carbone ET. Association of the dietary inflammatory index with depressive symptoms among pre- and post-menopausal women: findings from the National Health and Nutrition Examination Survey (NHANES) 2005–2010. Nutrients. 2022;14(9):1980. https://doi.org/10.3390/nu14091980.
14 C Pillay O, Manyonda I. The surgical menopause. Best Pract Res Clin Obstet Gynaecol. 2022;81:111–8. https://doi.org/10.1016/j.bpobgyn.2022.03.001.
15. Rodriguez M, Shoupe D. Surgical Menopause. Endocrinol Metab Clin North Am. 2015;44(3):531–42. https://doi.org/10.1016/j.ecl.2015.05.003.
16. Gower BA, Muñoz J, Desmond R, Hilario-Hailey T, Jiao X. Changes in intra-abdominal fat in early postmenopausal women: effects of hormone use. Obes Silver Spring Md. 2006;14(6):1046–55. https://doi.org/10.1038/oby.2006.120.
17. Yüksel H, Odabasi AR, Demircan S, Köseoğlu K, Kizilkaya K, Onur E. Effects of postmenopausal hormone replacement therapy on body fat composition. Gynecol Endocrinol Off J Int Soc Gynecol Endocrinol. 2007;23(2):99–104. https://doi.org/10.1080/09513590601152177.
18. Cavallino V, Rankin E, Popescu A, Gopang M, Hale L, Meliker JR. Antimony and sleep health outcomes: NHANES 2009–2016. Sleep Health. 2022;8(4):373–9. https://doi.org/10.1016/j.sleh.2022.05.005.
19. Giles WH, Croft JB, Keenan NL, Lane MJ, Wheeler FC. The validity of self-reported hypertension and correlates of hypertension awareness among blacks and whites within the stroke belt. Am J Prev Med. 1995;11(3):163–9.
20. Martin LM, Leff M, Calonge N, Garrett C, Nelson DE. Validation of self-reported chronic conditions and health services in a managed care population. Am J Prev Med. 2000;18(3):215–8. https://doi.org/10.1016/s0749-3797(99)00158-0.
21. Casagrande SS, Cowie CC, Genuth SM. Self-reported prevalence of diabetes screening in the U.S., 2005–2010. Am J Prev Med. 2014;47(6):780–7. https://doi.org/10.1016/j.amepre.2014.07.039.
22. Imai K, Keele L, Tingley D. A general approach to causal mediation analysis. Psychol Methods. 2010;15(4):309–34. https://doi.org/10.1037/a0020761.
23. 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. https://doi.org/10.1093/aje/kws342.
24. Heinzer R, Vat S, Marques-Vidal P, et al. Prevalence of sleep-disordered breathing in the general population: the HypnoLaus study. Lancet Respir Med. 2015;3(4):310–8. https://doi.org/10.1016/S2213-2600(15)00043-0.
25. Krüger M, Obst A, Ittermann T, et al. Menopause Is Associated with Obstructive Sleep Apnea in a Population-Based Sample from Mecklenburg-Western Pomerania, Germany. J Clin Med. 2023;12(6):2101. https://doi.org/10.3390/jcm12062101.
26. Zolfaghari S, Yao C, Thompson C, et al. Effects of menopause on sleep quality and sleep disorders: Canadian Longitudinal Study on Aging. Menopause N Y N. 2020;27(3):295–304. https://doi.org/10.1097/GME.0000000000001462.
27. Netzer NC, Eliasson AH, Strohl KP. Women with sleep apnea have lower levels of sex hormones. Sleep Breath Schlaf Atm. 2003;7(1):25–9. https://doi.org/10.1007/s11325-003-0025-8.

28. Huang T, Lin BM, Redline S, Curhan GC, Hu FB, Tworoger SS. Type of menopause, age at menopause, and risk of developing obstructive sleep apnea in postmenopausal women. Am J Epidemiol. 2018;187(7):1370–9. https://doi.org/10.1093/aje/kwy011.
29. Judd HL, Judd GE, Lucas WE, Yen SS. Endocrine function of the postmenopausal ovary: concentration of androgens and estrogens in ovarian and peripheral vein blood. J Clin Endocrinol Metab. 1974;39(6):1020–4. https://doi.org/10.1210/jcem-39-6-1020.
30. Fogle RH, Stanczyk FZ, Zhang X, Paulson RJ. Ovarian androgen production in postmenopausal women. J Clin Endocrinol Metab. 2007;92(8):3040–3. https://doi.org/10.1210/jc.2007-0581.
31. Resta O, Caratozzolo G, Pannacciulli N, et al. Gender, age and menopause effects on the prevalence and the characteristics of obstructive sleep apnea in obesity. Eur J Clin Invest. 2003;33(12):1084–9. https://doi.org/10.1111/j.1365-2362.2003.01278.x.
32. Young T, Finn L, Austin D, Peterson A. Menopausal status and sleep-disordered breathing in the Wisconsin sleep cohort study. Am J Respir Crit Care Med. 2003;167(9):1181–5. https://doi.org/10.1164/rccm.200209-1055OC.
33. Pillar G, Malhotra A, Fogel R, Beauregard J, Schnall R, White DP. Airway mechanics and ventilation in response to resistive loading during sleep: influence of gender. Am J Respir Crit Care Med. 2000;162(5):1627–32. https://doi.org/10.1164/ajrccm.162.5.2003131.
34 Popovic RM, White DP. Upper airway muscle activity in normal women: influence of hormonal status. J Appl Physiol Bethesda Md 1985. 1998;84(3):1055–62. https://doi.org/10.1152/jappl.1998.84.3.1055.
35. Hou YX, Jia SS, Liu YH. 17beta-Estradiol accentuates contractility of rat genioglossal muscle via regulation of estrogen receptor alpha. Arch Oral Biol. 2010;55(4):309–17. https://doi.org/10.1016/j.archoralbio.2010.02.002.
36. Andersen ML, Bittencourt LRA, Antunes IB, Tufik S. Effects of progesterone on sleep: a possible pharmacological treatment for sleep-breathing disorders? Curr Med Chem. 2006;13(29):3575–82. https://doi.org/10.2174/092986706779026200.
37 Bayliss DA, Millhorn DE. Central neural mechanisms of progesterone action: application to the respiratory system. J Appl Physiol Bethesda Md 1985. 1992;73(2):393–404. https://doi.org/10.1152/jappl.1992.73.2.393.
38. D'Angelo GF, De Mello AAF, Schorr F, et al. Muscle and visceral fat infiltration: a potential mechanism to explain the worsening of obstructive sleep apnea with age. Sleep Med. 2023;104:42–8. https://doi.org/10.1016/j.sleep.2023.02.011.
39. Williams CM. Lipid metabolism in women. Proc Nutr Soc. 2004;63(1):153–60. https://doi.org/10.1079/PNS2003314.
40. Tao Z, Zheng LD, Smith C, et al. Estradiol signaling mediates gender difference in visceral adiposity via autophagy. Cell Death Dis. 2018;9(3):309. https://doi.org/10.1038/s41419-018-0372-9.
41. Davis SR, Castelo-Branco C, Chedraui P, et al. Understanding weight gain at menopause. Climacteric. Published online October 1, 2012. Accessed May 19, 2024.https://www.tandfonline.com/doi/abs/10.3109/13697137.2012.707385.
42. Mirer AG, Young T, Palta M, Benca RM, Rasmuson A, Peppard PE. Sleep-disordered breathing and the menopausal transition among participants in the Sleep in Midlife Women Study. Menopause N Y N. 2017;24(2):157–62. https://doi.org/10.1097/GME.0000000000000744.
43. Shinohara E, Kihara S, Yamashita S, et al. Visceral fat accumulation as an important risk factor for obstructive sleep apnoea syndrome in obese subjects. J Intern Med. 1997;241(1):11–8. https://doi.org/10.1046/j.1365-2796.1997.63889000.x.
44. Sekizuka H, Ono Y, Saitoh T, Ono Y. Visceral fat area by abdominal bioelectrical impedance analysis as a risk of obstructive sleep apnea. Int Heart J. 2021;62(5):1091–5. https://doi.org/10.1536/ihj.21-219.
45. Hoffstein V, Zamel N, Phillipson EA. Lung volume dependence of pharyngeal cross-sectional area in patients with obstructive sleep apnea. Am Rev Respir Dis. 1984;130(2):175–8. https://doi.org/10.1164/arrd.1984.130.2.175.
46. Resta O, Bonfitto P, Sabato R, De Pergola G, Barbaro MPF. Prevalence of obstructive sleep apnoea in a sample of obese women: effect of menopause. Diabetes Nutr Metab. 2004;17(5):296–303.
47. Sc H, S W, Sg C, A S. Menopausal transition and changes of body composition: a prospective study in Chinese perimenopausal women. Int J Obes 2005. 2010;34(8).https://doi.org/10.1038/ijo.2010.33.
48. Trikudanathan S, Pedley A, Massaro JM, et al. Association of female reproductive factors with body composition: The Framingham Heart Study. J Clin Endocrinol Metab. 2013;98(1):236–44. https://doi.org/10.1210/jc.2012-1785.
49. Trémollieres FA, Pouilles JM, Ribot CA. Relative influence of age and menopause on total and regional body composition changes in postmenopausal women. Am J Obstet Gynecol. 1996;175(6):1594–600. https://doi.org/10.1016/S0002-9378(96)70111-4.
50. Ambikairajah A, Walsh E, Tabatabaei-Jafari H, Cherbuin N. Fat mass changes during menopause: a metaanalysis. Am J Obstet Gynecol. 2019;221(5):393-409.e50. https://doi.org/10.1016/j.ajog.2019.04.023.
51. Basoglu OK, Tasbakan MS. Gender differences in clinical and polysomnographic features of obstructive sleep apnea: a clinical study of 2827 patients. Sleep Breath. 2018;22(1):241–9. https://doi.org/10.1007/s11325-017-1482-9.
52. Fujioka S, Matsuzawa Y, Tokunaga K, Keno Y, Kobatake T, Tarui S. Treatment of visceral fat obesity. Int J Obes. 1991;15(Suppl 2):59–65.
53. Haganes KL, Silva CP, Eyjólfsdóttir SK, et al. Time-restricted eating and exercise training improve HbA1c and body composition in women with overweight/obesity: a randomized controlled trial. Cell Metab. 2022;34(10):1457-1471.e4. https://doi.org/10.1016/j.cmet.2022.09.003.

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