Published in final edited form as:

Sleep Med. 2016 October ; 26: 46–53. doi:10.1016/j.sleep.2015.06.003.

Racial/Ethnic Differences in the Associations between Obesity Measures and Severity of Sleep-Disordered Breathing: The Multi-Ethnic Study of Atherosclerosis

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Abstract

Objectives—To evaluate associations between obesity measures and sleep-disordered breathing severity among White, Black, Hispanic, and Chinese Americans.

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Conflict of Interest

All authors have no conflict of interest in relation to the work described.

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Methods—A community-based cross-sectional study of 2053 racially/ethnically diverse adults in the Multiethnic Study of Atherosclerosis. Anthropometry and polysomnography were used to measure obesity and apnea-hypopnea index (AHI). Linear regression models were fitted to investigate associations of BMI and waist circumference with AHI (log-transformed) with adjustment for sociodemographics, lifestyle factors, and comorbidities.

Results—Mean participant age was 68.4 (range: 54–93) years; 53.6% of participants were women. Median AHI was 9.1 events/hour. There were significant associations of BMI and waist circumference with AHI in the overall cohort and within each racial/ethnic group. A significant interaction was observed between race/ethnicity and BMI ($P_{\text{interaction}}=0.017$). Models predicted that for each unit increase in BMI (kg/m^2), mean AHI increased by 19.7% for Chinese, 11.6% for Whites and Blacks, and 10.5% for Hispanics. Similarly, incremental changes in waist circumference were associated with larger increases in AHI among Chinese than other groups.

Conclusions—Associations of BMI and waist circumference with AHI were stronger among Chinese than other racial/ethnic groups. These findings highlight a potential emergence of elevated sleep-disordered breathing prevalence occurring in association with increasing obesity in Asian populations.

Keywords

sleep-disordered breathing; obesity; body mass index; waist circumference; race/ethnicity; apnea-hypopnea index; polysomnography

INTRODUCTION

The burdens of obesity and sleep-disordered breathing (SDB) are disproportionately borne by racial/ethnic minorities in the United States [1, 2]. Both obesity and SDB are associated with hypertension, diabetes, cardiovascular disease (CVD), and mortality [3–8]. Previous studies have shown some variation in the prevalence and severity of SDB by race/ethnicity [9–11]. For example, in a cross-sectional study of 308 obese patients with body mass index (BMI) $\geq 35 \text{ kg}/\text{m}^2$, South Asians had a significantly higher prevalence and more severe SDB than White Europeans [11]. Our recent findings in the Multiethnic Study of Atherosclerosis (MESA) indicate that SDB is prevalent among middle-aged and older US adults, and that Hispanics and Chinese have higher odds of SDB than Whites after considering the influence of BMI [12]. Although SDB appears to vary by race/ethnicity, the basis for this variation is unclear.

Obesity is a strong risk factor for SDB. Although the association between obesity and SDB has been well established in the literature, less is known regarding whether the strength of this association varies across racial/ethnic groups. Sands-Lincoln and colleagues showed that the relationship between sleep apnea and hypertension depended on race/ethnicity and obesity [8]. There may be a complex association among SDB, race/ethnicity, and obesity. Furthermore, other risk factors for SDB, such as craniofacial structure, upper airway collapsibility, and ventilatory control, may also vary across population groups [13]. Since BMI and body fat distribution vary by race/ethnicity [14], it is important to understand whether group differences in SDB are related to differences in levels of BMI or to

differences in central obesity (as measured by waist circumference), or to propensity for SDB with incremental increases in body weight. This information may help identify risk factors that confer increased SDB within racial/ethnic groups and also may help develop targeted intervention strategies.

This study aimed to better understand how variation in body weight and body fat distribution were associated with SDB severity within racial/ethnic groups after adjustment for possible confounders, including sociodemographic factors, physical activity, smoking status, and comorbidities. We also sought to explore potential variation in these associations by age and sex. We systematically evaluated the associations of general (BMI) and abdominal obesity (waist circumference) measures with polysomnography (PSG)-measured SDB severity across four racial/ethnic groups (White, Black, Hispanic, and Chinese Americans). Waist circumference has been considered a simple and valuable anthropometric measure of abdominal obesity [15]. As age and sex are related to obesity and SDB severity [1, 6], we conducted exploratory analyses to examine the potential 3-way interactions of age, sex, and race/ethnicity with BMI and waist circumference pertaining to SDB severity.

METHODS

Study Design and Participants

MESA is a multi-site prospective study designed to investigate the prevalence and progression of subclinical CVD and to identify risk factors for incident CVD in a racially/ethnically diverse sample. The description of the study design for MESA has been published [16]. Briefly, between 2000 and 2002, a total of 6814 men and women who identified themselves as White, Black/African-American, Hispanic, or Chinese aged 45–84 years and free of clinically apparent CVD were recruited from six US communities: Baltimore City and Baltimore County, Maryland; Chicago, Illinois; Forsyth County, North Carolina; Los Angeles, California; New York, New York; and St. Paul, Minnesota. At the MESA Exam 5 between 2010 and 2013, 10 years after the initial exam, all MESA participants other than those reporting regular use of oral devices, nocturnal oxygen, or nightly positive airway pressure devices were invited to participate in the MESA Sleep Ancillary Study, which consisted of PSG, actigraphy, and sleep questionnaire data collected during an in-home examination. Of 4077 participants approached, 147 (6.5%) were ineligible (95 due to a history of use of positive airway pressure (2%); 4 due to use of an oral appliance; and 4 due to oxygen use) and 141 participants lived too far away to participate. Of the remaining 3789 participants, 2261 participated in the sleep exam (59.7%). In total, 2060 participants successfully completed the PSG examination. Of these, 2053 participants had complete data for PSG, demographic characteristics including sex and age, and BMI. Although 2050 participants had data on waist circumference, 4 participants were outliers with extreme waist circumference values (e.g., 195 cm) and were thus excluded. A total of 2046 participants were available for waist circumference analyses.

Institutional Review Board approval was obtained at each study site and written informed consent was obtained from all participants.

Measures of SDB

PSG was conducted using a 15-channel monitor (Compumedics Somte ® System; Compumedics Ltd., Abbotsville, AU). The recording montage included electroencephalography (EEG), bilateral electrooculograms, a chin electromyography, bipolar electrocardiogram, thoracic and abdominal respiratory inductance plethysmography, airflow measured by thermocouple and nasal pressure cannula, finger pulse oximetry, and bilateral limb movements. PSG provided quantitative assessments of levels of overnight hypoxemia, apneas and hypopneas, and sleep stage distributions. Sleep stages and EEG (cortical) arousals were scored according to published guidelines [17]. Apneas were scored when the thermocouple signal flattened or nearly flattened for 10 seconds or more. Hypopneas were scored when the amplitude of the sum of the abdominal and thoracic inductance signals or the nasal pressure flow signal decreased by 30% or more for greater than or equal to 10 seconds. Events were classified as either “central” or “obstructive” according to the presence or absence of respiratory effort. Specialized software link apneas and hypopneas with data from the oxygen saturation and EEG signals allowed each event to be characterized according to the degree of associated desaturation. Apnea-hypopnea index (AHI) was calculated to evaluate SDB severity based on the average number of all obstructive apneas, all central apneas, and hypopneas associated with a $\geq 4\%$ desaturation per hour of sleep.

Anthropometry

Trained research personnel conducted anthropometric measurements that included weight, height, and waist circumference. Weight and height were measured with participants wearing light clothing without shoes. Waist circumference was measured in cm at the level of the umbilicus [18]. Measured weight and height were used to calculate BMI as a measure of general obesity. Measured waist circumference was assessed as a measure of abdominal obesity.

Sociodemographic and Lifestyle Characteristics

Participants provided information on age, sex, educational attainment, and income. Six study sites included Baltimore, Chicago, Forsyth County, Los Angeles, New York, and St. Paul. Race/ethnicity was self-identified and categorized as: White, Black/African-American, Hispanic, and Chinese. Lifestyle behaviors included physical activity and smoking status determined from questionnaires. The sum of minutes per week spent engaged in moderate and vigorous physical activity types was multiplied by the metabolic equivalent (MET) level and physical activity level was expressed as MET-minute/week [19]. Current smoking status was defined as having smoked a cigarette in the last 30 days, and was categorized as never smoked, former smoker, and current smoker.

Comorbidities

We considered hypertension and diabetes as potential confounders. Hypertension was defined as a systolic blood pressure ≥ 140 mm Hg, diastolic blood pressure ≥ 90 mm Hg based on measurements from trained staff, or self-reported use of any antihypertensive

medication [20]. Diabetes was defined as fasting plasma glucose ≥ 126 mg/dL or self-reported use of a diabetes medication [20].

Statistical Analysis

Analysis of variance was used to evaluate mean differences for continuous variables (e.g., age, BMI) across racial/ethnic groups. As AHI was not normally distributed, the Kruskal-Wallis test was conducted for AHI. Chi-square tests were used to evaluate differences in the distributions of categorical variables including sociodemographic characteristics across racial/ethnic groups. Univariate and multivariable linear regression models were fitted to investigate the associations between BMI, waist circumference, and AHI (natural log-transformed) across racial/ethnic groups. We fitted several sets of models to minimally (age-, sex-, and study site- adjusted) and fully adjust for potential confounders including age, sex, race/ethnicity, educational attainment, income, hypertension, diabetes, physical activity, smoking status, and study site. Examination of whether the relationships between BMI and waist circumference and log-transformed AHI were linear was conducted through visual inspection of the scatterplot with a fitted locally weighted scatterplot smoothing (LOWESS) curve and through assessment of whether adding a quadratic term improved the model fits.

We explored whether the association between AHI and anthropometric measures varied by race/ethnicity in the overall population and further by sex- (men vs. women) or age- (median=67 years as cut-point, <67 vs. ≥ 67 years) specific subpopulation by testing the appropriate interaction terms in the model and comparing the magnitude of associations across subgroups. Pairwise comparisons were conducted to identify the differential pattern among subgroups. As there were no Chinese with BMI ≥ 40 kg/m² in this study, we conducted sensitivity analyses by excluding 77 individuals (19 Whites, 35 Blacks, and 23 Hispanics) with BMI ≥ 40 kg/m² so as to avoid the influence of extreme morbid obesity on fitted models.

Analyses were performed using SAS 9.3 (SAS Institute, Cary, North Carolina). Statistical significance levels were set *a priori* at $\alpha < 0.05$, and all reported P-values are from 2-sided tests.

RESULTS

Participant Characteristics

Table 1 displays sociodemographic and clinical characteristics of study participants by race/ethnicity. Participants were on average 68.4 (standard deviation [SD]: 9.1) years old; 53.6% of participants were female. Mean BMI was lowest for Chinese (mean=24.2; SD=3.3), followed by Whites (mean=28.0; SD=5.2), Hispanics (mean=30.0; SD=5.5), and Blacks (mean=30.3; SD=5.6). Mean waist circumference was also lowest for Chinese, followed by Whites, Hispanics, and Blacks. Median AHI was 9.1 (interquartile range (IQR): 3.3–19.6) events/hour, with the highest median value for Hispanics (11.1; IQR=4.3–22.4), followed by Chinese (10.3; IQR=3.6–21.7), Blacks (8.5; IQR=2.8–19.2), and Whites (7.5; IQR=2.9–17.3). Similarly, the mean of log-transformed AHI was highest for Hispanics (2.14;

SD=1.46), followed by Chinese (1.95; SD=1.73), Blacks (1.85; SD=1.70), and Whites (1.81; SD=1.57).

Associations between Obesity Measures and AHI across Racial/Ethnic Groups

As models with inclusion of quadratic terms of BMI and waist circumference for log-transformed AHI did not improve the model fit substantially (changes in R-square and adjusted R-square less than 0.02%) and LOWESS analysis indicated that the associations of BMI and waist circumference with log-transformed AHI appeared to be linear, we present subsequent results based on linear regression models without quadratic terms.

As shown in Table 2, there were significant and positive associations between BMI and log-transformed AHI in the overall cohort and within each racial/ethnic group, but with varying magnitudes. In the fully adjusted model, the beta estimate reflecting increase in the log-transformed AHI corresponding to one unit increase in BMI was highest for Chinese (beta=0.18, standard error [SE]=0.03), followed by Whites (beta=0.11, SE=0.01) and Blacks (beta=0.11, SE=0.01), and Hispanics (beta=0.10, SE=0.01) ($P_{interaction}=0.017$). In other words, the model predicted that for each unit increase in BMI (kg/m^2), the mean AHI increased by 19.7% for Chinese, 11.6% for Whites and Blacks, and 10.5% for Hispanics. Further stratified analyses by age or sex suggested that these associations were stronger among Chinese women or younger Chinese (<67 years old) compared to other groups (Figure 1), although the 3-way interaction terms for age or sex were not statistically significant ($P_{interaction}=0.17$ and 0.15 respectively). The results were consistent across a range of fitted models, from the minimally adjusted model to the fully adjusted model.

A sensitivity analysis that excluded participants with a BMI $\geq 40 \text{ kg/m}^2$ showed similar results (Supplementary Table 1).

We fitted another set of models to waist circumference and log-transformed AHI, and found similar results (Table 3) to the BMI-AHI association. For example, the association between waist circumference and log-transformed AHI was strongest for Chinese (fully adjusted beta=0.05, SE=0.01), followed by Whites (beta=0.04, SE=0.004) and Blacks (beta=0.04, SE=0.005), and Hispanics (beta=0.03; SE=0.005). For each unit increase in waist circumference (cm), AHI increased by 5.1% for Chinese, 4.1% for Whites and Blacks, and 3.0% for Hispanics. The positive association between waist circumference and AHI was stronger among Chinese women as compared with other groups (Figure 2; $P_{interaction} = 0.028$). The association also appeared to be stronger among younger Chinese, although the 3-way interaction was not significant ($P_{interaction} = 0.135$). Results were consistent across a range of fitted models, from the minimally adjusted model to the fully adjusted model.

DISCUSSION

A comparison of the prevalence and risk factors for SDB across racial/ethnic groups can be helpful for identifying social, environmental, and genetic factors that may contribute to SDB. However, to date, few studies have explored the complex associations between race/ethnicity, obesity measures, and SDB severity in direct inter-ethnic comparisons. Given the availability of rigorously collected PSG data as well as anthropometric measures in a

relatively large multi-ethnic cohort, we were able to estimate the racial/ethnic variation in the associations of BMI and waist circumference with AHI. Our analyses confirmed positive and significant associations of BMI and waist circumference with AHI levels in all racial/ethnic groups studied. Moreover, we identified a stronger association of increasing BMI and waist circumference with AHI among Chinese compared to Whites, Blacks, and Hispanics. Furthermore, we found that the associations between measures of adiposity and AHI were not explained by sociodemographic variables, comorbidities, or lifestyle behaviors including physical activity or smoking status. Our findings also suggest that increased levels of adiposity are associated with particularly large mean log-transformed AHI increases among Chinese women and Chinese individuals aged < 67 years. Overall, these findings support the importance of adiposity as a risk factor for SDB across racial/ethnic groups, and suggest that some groups, such as Chinese, may be particularly susceptible to the adverse effects of obesity.

The emergence of obesity as a global health epidemic [22] supports the importance of research that addresses the impact of obesity on health outcomes such as SDB across population groups. Obesity is highly prevalent worldwide including in Asian countries [22] as well as developed countries such as the United States [1, 23]. The worldwide prevalence of obesity has more than doubled since 1980. In 2014, more than 1.9 billion (39%) adults aged 18 years and over were overweight, and over 600 million (13%) adults were obese [23]. In most Asian countries, the prevalence of overweight and obesity has increased substantially in the past several decades [21]. Our data confirm previous studies indicating the importance of obesity as a risk factor for SDB [9]. Furthermore, the finding of stronger associations between adiposity and SDB severity in Chinese suggest the particular importance of changes in adiposity influencing the health of Chinese populations. Asian populations are at increased risk for diabetes and CVD [25], which are also associated with SDB [6]. Thus, our findings provide support for weight management optimization even among groups such as Chinese with relatively low prevalence of obesity comparatively.

Other studies have suggested a higher prevalence and greater severity of SDB among Asians than in Whites [11, 26, 27] and that SDB risk in Asians may be influenced by craniofacial structural factors that also reduce upper airway patency [28, 29]. Obesity and craniofacial factors may contribute differentially to SDB severity in Chinese and Whites with SDB [30]. In a study conducted at two sleep disorder clinics among 150 patients with SDB in Australia and Hong Kong [30], Lee et al reported that Chinese patients had more severe SDB (AHI 35.3 vs 25.2 events/hour) and more craniofacial bony restriction including a shorter cranial base (63.6 vs 77.5 mm), maxilla (50.7 vs 58.8 mm) and mandible length (65.4 vs 77.9 mm) than White patients. For the same degree of SDB severity, Whites had a higher BMI (30.7 vs 28.4 kg/m²) and larger neck circumference (40.8 vs 39.1 cm) than Chinese [30]. These results are consistent with our data that indicate that smaller increases in BMI or waist circumference are associated with higher AHI levels among Chinese than Whites. They also provide support to the possibility that in the presence of an anatomically smaller airway, smaller BMI and/or waist circumference changes may result in greater SDB severity.

Prior literature has suggested that Blacks have an increased prevalence of SDB compared to Whites, although this association appears strongest among children and young adults and

attenuates in older individuals [2, 31]. These data suggest the early life influences such as exposure to airway irritants or allergens that contribute to adenotonsillar hypertrophy and adversely impact upper airway patency may disproportionately affect Black children [31]. In our sample, although adult Blacks had on average the highest BMI values, they did not have the highest AHI levels. It has been suggested that there may be a “healthy obese” phenotype and that relative to other populations, obesity may be associated with a lower prevalence of metabolic disturbances in Blacks [32, 33]. Additional research is needed to determine if obesity is similarly associated with a lower risk of SDB in Black relative to other populations.

Increasing evidence suggests that environmental factors associated with socioeconomic class [34] and physical activity [35, 36] may influence SDB, and that these factors might confound associations among race, obesity and SDB. We used the rich MESA data set to control for these variables. We also controlled for hypertension and diabetes, co-morbidities that are common in both obesity and SDB [6]. The stability of our estimates across models suggests that the relationship between adiposity and SDB severity are unlikely to reflect confounding. We also explored potential differences in associations across age and sex stratum. Although we had limited power to detect 3-way interactions, our results suggested that adiposity most strongly influenced SDB severity in Chinese women and Chinese younger than age 67 years. Prior research has identified that both age and sex may modify the association between SDB and cardiovascular outcomes [37, 38]. Such differences have been attributed to the different influences of sex hormones, comorbidities, and disease duration on SDB outcomes. Although the results of the subgroup analyses should be interpreted cautiously, they support the need for future research that considers differences in SDB pathogenesis and consequences across the age spectrum in males and females.

Our study has important strengths. To our knowledge, this is the first study to examine the associations between race/ethnicity, general and abdominal obesity parameters, and PSG-measured SDB severity among a relatively large cohort of middle-aged and older Whites, Blacks, Hispanics, and Chinese Americans. We examined the complex associations using complementary statistical analysis strategies, as well as evaluated the potential 3-way interactions of age, sex, and race/ethnicity with two measures of adiposity (BMI and waist circumference) for AHI. We also considered and controlled for sociodemographic and lifestyle factors and comorbidities in the models. The findings were robust with adjustment for age, sex, and study site as well as further adjustment for socioeconomic and lifestyle factors, suggesting that the racial/ethnic differences were unlikely explained by these factors.

Despite these strengths, this study has limitations. The cross-sectional study design may have resulted in selection bias, and prevents examination of temporality. Although the characteristics of participants and non-participants in the MESA sleep exam were comparable, we cannot exclude participation bias in the ancillary sleep study, including differential participation by members of each racial/ethnic group. We have no access to dietary intake data or sleep disorders screening. Diet quality has been associated with SDB independent of obesity [39]. We did not measure neck circumference, visceral fat, or craniofacial anatomy. Although direct information on health care access, which could influence sleep apnea screening was unavailable, adjustment for two proxy variables,

education and income, did not change our results. Finally, we do not have longitudinal data to identify how prospective changes in weight influence SDB severity.

In summary, our results indicate that despite relatively low levels of BMI and central obesity among Chinese, incremental increases in BMI and waist circumference are associated with larger increases in SDB severity than in the other race/ethnic groups studied. These observations suggest that Chinese, and possibly other Asian populations, may be particularly susceptible to SDB as adiposity levels increase. Targeting optimal weight levels may thus be particularly advantageous to Chinese populations. Longitudinal data are needed to better understand the role of prospective changes in adiposity on SDB risk.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

The Multi-Ethnic Study of Atherosclerosis (MESA) is supported by contracts N01-HC-95159 through N01-HC-95169 from the National Heart, Lung, and Blood Institute (NHLBI) at the National Institutes of Health. The work presented in this paper was supported by grants from NIH 1R01HL083075-01, R01HL098433, R01HL098433-02S1, 1U34HL105277-01, 1R01HL110068-01A1 1R01HL113338-01, R21 HL108226, P20 NS076965, 3R01HL115941-01S1, UL1TR001102, 5T32HL007901, and R01 HL109493. This work was also supported by an award from the National Center for Advancing Translational Sciences (NCATS): 8UL1TR000170-07. The authors would like to thank the other investigators, staff, and participants of the MESA study for their valuable contributions. The authors would also like to thank Jia Weng for his assistance in creating figures. A full list of participating MESA investigators and institutions can be found at <http://www.mesa-nhlbi.org>.

ABBREVIATIONS

AHI	apnea-hypopnea index
BMI	body mass index
CI	confidence interval
CVD	cardiovascular disease
EEG	electroencephalography
IQR	interquartile range
LOWESS	locally weighted scatterplot smoothing
MESA	Multi-Ethnic Study of Atherosclerosis
MET	metabolic equivalent
PSG	polysomnography
SDB	sleep-disordered breathing
SD	standard deviation
SE	standard error

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Highlights

- We studied associations of obesity measures with sleep apnea severity in US adults.
- Body mass index and waist circumference were related to apnea-hypopnea index in all racial/ethnic groups.
- These associations were stronger in Chinese than in Whites, Blacks, and Hispanics.
- Associations were not explained by sociodemographics, comorbidities, or lifestyles.

Figure 1. Pairwise comparisons of the association between body mass index and log-transformed apnea-hypopnea index across racial/ethnic groups

Horizontal lines represent 95% confidence intervals for the difference in association between the two comparison groups (A–B for A vs. B). The following variables were adjusted for: age, sex (except for stratified analysis), income, education, hypertension, diabetes, smoking status, physical activity, and study site.

Figure 2. Pairwise comparisons of the association between waist circumference and log-transformed apnea-hypopnea index across racial/ethnic groups

Horizontal lines represent 95% confidence intervals for the difference in association between the two comparison groups (A–B for A vs. B). The following variables were adjusted for: age, sex (except for stratified analysis), income, education, hypertension, diabetes, smoking status, physical activity, and study site.

Table 1

Sociodemographic and clinical characteristics of study participants across racial/ethnic groups: the MESA 2010–2013 (n = 2053)

	Total (n = 2053)	White (n = 740)	Black (n = 574)	Hispanic (n = 490)	Chinese (n = 249)	P value ^a
Age, years, mean (SD)	68.4 (9.1)	68.4 (9.1)	68.8 (9.1)	68.4 (9.4)	67.8 (9.1)	0.675
Female, %	53.6	53.7	55.2	53.3	50.6	0.689
Education, %						
< High school	15.1	3.3	7.7	40.0	18.1	<0.001
High school	16.3	14.4	16.1	20.6	13.7	
Technical school, associate degree, some college	29.3	24.3	39.7	28.0	22.9	
College or higher degree	39.4	58.1	36.5	11.4	45.4	
Income, %						
< \$20,000	20.7	7.6	17.2	36.6	36.2	<0.001
\$20,000–\$39,999	24.8	17.9	30.3	31.9	18.7	
\$40,000–\$74,999	26.2	30.7	27.1	21.4	20.3	
\$75,000	28.3	43.8	25.5	10.1	24.8	
Study site, %						
Baltimore, Maryland (MD)	14.8	19.5	27.7	0.0	0.0	<0.001
Chicago, Illinois (IL)	18.7	22.6	17.3	0.0	47.4	
Forsyth County, North Carolina (NC)	14.5	17.0	29.6	0.2	0.0	
Los Angeles, California (CA)	16.7	5.0	6.6	27.8	52.6	
New York, New York (NY)	18.0	9.3	18.8	39.2	0.0	
St. Paul, Minnesota (MN)	17.4	26.6	0.0	32.9	0.0	
Physical activity (MET-minute/week), median (IQR) ^b	3637 (1725–7159)	3780 (2040–6900)	3795 (1950–7920)	3116 (1200–7597)	3285 (1597–5403)	<0.001
Current smoker, %	6.6	5.7	11.0	4.8	2.9	<0.001
Hypertension ^c , %	56.7	48.5	71.8	56.7	46.2	<0.001
Diabetes ^d , %	19.9	11.3	26.7	27.3	15.5	0.001
BMI, kg/m ² , mean (SD)	28.7 (5.5)	28.0 (5.2)	30.3 (5.6)	30.0 (5.5)	24.2 (3.3)	<0.001
Waist circumference, cm, mean (SD)	99.3 (14.3)	98.9 (14.9)	102.8 (14.0)	101.7 (13.4)	88.4 (9.7)	<0.001
AHI, events/h, median (IQR)	9.1 (3.3–19.6)	7.5 (2.9–17.3)	8.5 (2.8–19.2)	11.1 (4.3–22.4)	10.3 (3.6–21.7)	<0.001
AHI (natural log transformation), mean (SD)	1.92 (1.61)	1.81 (1.57)	1.85 (1.70)	2.14 (1.46)	1.95 (1.73)	0.004

Abbreviations: AHI, apnea-hypopnea index; BMI, body mass index; IQR, interquartile range; SD, standard deviation; SDB, sleep-disordered breathing.

p values were from analysis of variance for continuous variables and chi-square test for categorical variables. As AHI was not normally distributed, the P value was from the Kruskal-Wallis test for AHI.

q Moderate/vigorous physical activity.

c Hypertension was defined as a systolic blood pressure $\geq$ 140 mm Hg, diastolic blood pressure $\geq$ 90 mm Hg, or the use of any antihypertensive medication.

d Diabetes was defined as fasting plasma glucose $\geq$ 126 mg/dL or the use of a diabetes medication.

Associations between body mass index and apnea-hypopnea index (log-transformed) within racial/ethnic groups: the MESA 2010–2013

Table 2

Dependent variable: log-transformed AHI	Unadjusted			Age-, sex-, site-adjusted ^a			Age-, sex-, site-, smoking-, and PA-adjusted ^b			Fully adjusted ^c		
	N	Beta (SE)	P value	N	Beta (SE)	P value	N	Beta (SE)	P value	N	Beta (SE)	P value
BMI (kg/m ²)	2053	0.09 (0.01)	<0.001	2053	0.11 (0.01)	<0.001	2025	0.11 (0.01)	<0.001	2006	0.11 (0.01)	<0.001
By race/ethnicity												
White	740	0.11 (0.01)	<0.001	740	0.12 (0.01)	<0.001	734	0.12 (0.01)	<0.001	730	0.11 (0.01)	<0.001
Black	574	0.09 (0.01)	<0.001	574	0.10 (0.01)	<0.001	563	0.10 (0.01)	<0.001	555	0.11 (0.01)	<0.001
Hispanic	490	0.08 (0.01)	<0.001	490	0.09 (0.01)	<0.001	482	0.10 (0.01)	<0.001	479	0.10 (0.01)	<0.001
Chinese	249	0.19 (0.03)	<0.001	249	0.18 (0.03)	<0.001	246	0.18 (0.03)	<0.001	242	0.18 (0.03)	<0.001
<i>P</i> _{Interaction (race*BMI)}			0.003			0.022			0.020			0.017
By sex and race/ethnicity												
Men												
White	343	0.11 (0.02)	<0.001	343	0.12 (0.02)	<0.001	339	0.12 (0.02)	<0.001	338	0.12 (0.02)	<0.001
Black	257	0.12 (0.02)	<0.001	257	0.12 (0.02)	<0.001	251	0.13 (0.02)	<0.001	249	0.12 (0.02)	<0.001
Hispanic	229	0.09 (0.02)	<0.001	229	0.10 (0.02)	<0.001	225	0.09 (0.02)	<0.001	223	0.10 (0.02)	<0.001
Chinese	123	0.08 (0.03)	0.010	123	0.10 (0.03)	0.002	121	0.10 (0.03)	0.004	120	0.09 (0.03)	0.006
Women												
White	397	0.11 (0.01)	<0.001	397	0.12 (0.01)	<0.001	395	0.12 (0.01)	<0.001	392	0.12 (0.02)	<0.001
Black	317	0.10 (0.02)	<0.001	317	0.11 (0.02)	<0.001	312	0.11 (0.02)	<0.001	306	0.11 (0.02)	<0.001
Hispanic	261	0.08 (0.01)	<0.001	261	0.09 (0.01)	<0.001	257	0.09 (0.01)	<0.001	256	0.09 (0.02)	<0.001
Chinese	126	0.24 (0.05)	<0.001	126	0.24 (0.05)	<0.001	125	0.25 (0.05)	<0.001	122	0.23 (0.05)	<0.001
<i>P</i> _{Interaction (race*sex*BMI)}			0.315			0.159			0.268			0.171
By age and race/ethnicity												
<67 years old												
White	377	0.13 (0.01)	<0.001	375	0.13 (0.01)	<0.001	377	0.13 (0.01)	<0.001	372	0.12 (0.02)	<0.001
Black	281	0.11 (0.02)	<0.001	281	0.13 (0.02)	<0.001	274	0.13 (0.02)	<0.001	274	0.13 (0.02)	<0.001
Hispanic	245	0.12 (0.02)	<0.001	245	0.13 (0.02)	<0.001	241	0.13 (0.02)	<0.001	240	0.14 (0.02)	<0.001
Chinese	125	0.28 (0.04)	<0.001	125	0.26 (0.04)	<0.001	124	0.26 (0.04)	<0.001	124	0.26 (0.04)	<0.001
67 years old												
White	363	0.09 (0.02)	<0.001	363	0.09 (0.02)	<0.001	359	0.09 (0.02)	<0.001	358	0.09 (0.02)	<0.001

Dependent variable: log-transformed AHI	Unadjusted			Age-, sex-, site-adjusted ^a			Age-, sex-, site-, smoking-, and PA-adjusted ^b			Fully adjusted ^c		
	N	Beta (SE)	P value	N	Beta (SE)	P value	N	Beta (SE)	P value	N	Beta (SE)	P value
Black	293	0.07 (0.02)	<0.001	293	0.09 (0.02)	<0.001	289	0.08 (0.02)	<0.001	281	0.07 (0.02)	<0.001
Hispanic	245	0.04 (0.01)	0.009	245	0.05 (0.02)	<0.001	241	0.05 (0.02)	<0.001	239	0.05 (0.02)	0.005
Chinese	124	0.09 (0.05)	0.099	124	0.09 (0.05)	0.049	122	0.10 (0.05)	0.034	118	0.08 (0.05)	0.110
<i>P_{interaction} (race*age*BMI)</i>			0.054			0.208			0.142			0.146

Abbreviations: AHI, apnea-hypopnea index; BMI, body mass index; PA, physical activity; SE, standard error.

^a Adjusted for age, sex, and study site (except for stratified analysis by sex and age groups).

^b Adjusted for age, sex, study site, smoking, and physical activity (except for stratified analysis by sex and age groups).

^c Adjusted for age, sex, race (except for stratified analysis), income, educational attainment, hypertension, diabetes, smoking status, physical activity, and study site.

Age and BMI were continuous variables. For stratified analysis by age, the cut point of 67 was the median of age in this study population.

In all models, the outcome variable apnea-hypopnea index (AHI) was with natural log transformation. As some confounders had missing data, the summed numbers for adjusted models might not be equal to the numbers as shown for unadjusted models.

The beta estimate reflecting increase in the log-transformed AHI corresponded to one unit increase in BMI.

Table 3

Associations between waist circumference and apnea-hypopnea index (log-transformed) within racial/ethnic groups: the MESA 2010–2013

Dependent variable: log-transformed AHI	Unadjusted			Age-, sex-, site-adjusted ^a			Age-, sex-, site-, smoking-, and PA-adjusted ^b			Fully adjusted ^c		
	N	Beta (SE)	P Value	N	Beta (SE)	P value	N	Beta (SE)	P value	N	Beta (SE)	P value
Waist circumference	2046	0.04 (0.002)	<0.001	2046	0.04 (0.002)	<0.001	2018	0.04 (0.002)	<0.001	1999	0.03 (0.003)	<0.001
By race/ethnicity												
Waist circumference												
White	735	0.04 (0.004)	<0.001	735	0.04 (0.004)	<0.001	729	0.04 (0.004)	<0.001	725	0.04 (0.004)	<0.001
Black	573	0.04 (0.005)	<0.001	573	0.04 (0.005)	<0.001	562	0.04 (0.005)	<0.001	554	0.04 (0.005)	<0.001
Hispanic	490	0.03 (0.005)	<0.001	490	0.03 (0.005)	<0.001	482	0.03 (0.005)	<0.001	479	0.03 (0.005)	<0.001
Chinese	248	0.06 (0.01)	<0.001	248	0.05 (0.01)	<0.001	245	0.05 (0.01)	<0.001	241	0.05 (0.01)	<0.001
$P_{\text{interaction}} (\text{race} * \text{WC})$			0.140			0.170			0.153			0.121
Waist circumference												
Men												
White	342	0.03 (0.01)	<0.001	342	0.04 (0.01)	<0.001	338	0.04 (0.01)	<0.001	337	0.04 (0.01)	<0.001
Black	256	0.04 (0.01)	<0.001	256	0.04 (0.01)	<0.001	250	0.05 (0.01)	<0.001	248	0.04 (0.01)	<0.001
Hispanic	229	0.03 (0.01)	<0.001	229	0.03 (0.01)	0.002	225	0.03 (0.01)	0.002	223	0.02 (0.01)	0.002
Chinese	122	0.02 (0.01)	0.068	122	0.02 (0.01)	0.068	120	0.02 (0.01)	0.084	119	0.02 (0.01)	0.106
Women												
White	393	0.04 (0.01)	<0.001	393	0.04 (0.01)	<0.001	391	0.04 (0.01)	<0.001	388	0.04 (0.01)	<0.001
Black	317	0.03 (0.01)	<0.001	317	0.04 (0.01)	<0.001	312	0.04 (0.01)	<0.001	306	0.03 (0.01)	<0.001
Hispanic	261	0.03 (0.01)	<0.001	261	0.03 (0.01)	<0.001	257	0.03 (0.01)	<0.001	256	0.03 (0.01)	<0.001
Chinese	126	0.07 (0.02)	<0.001	126	0.08 (0.02)	<0.001	125	0.08 (0.02)	<0.001	122	0.07 (0.02)	<0.001
$P_{\text{interaction}} (\text{race} * \text{sex} * \text{WC})$			0.057			0.029			0.051			0.028
By age and race/ethnicity												
<67 years old												
White	374	0.05 (0.01)	<0.001	374	0.05 (0.01)	<0.001	372	0.05 (0.01)	<0.001	369	0.04 (0.01)	<0.001
Black	280	0.05 (0.01)	<0.001	280	0.05 (0.01)	<0.001	273	0.05 (0.01)	<0.001	273	0.04 (0.01)	<0.001
Hispanic	245	0.05 (0.01)	<0.001	245	0.05 (0.01)	<0.001	241	0.05 (0.01)	<0.001	240	0.05 (0.01)	<0.001
Chinese	125	0.10 (0.01)	<0.001	125	0.09 (0.01)	<0.001	124	0.08 (0.02)	<0.001	124	0.08 (0.02)	<0.001
67 years old												

Dependent variable: log-transformed AHI	Unadjusted			Age-, sex-, site-adjusted ^a			Age-, sex-, site-, smoking-, and PA-adjusted ^b			Fully adjusted ^c		
	N	Beta (SE)	P Value	N	Beta (SE)	P value	N	Beta (SE)	P value	N	Beta (SE)	P value
White	361	0.03 (0.01)	<0.001	361	0.03 (0.01)	<0.001	357	0.03 (0.01)	<0.001	356	0.03 (0.01)	<0.001
Black	293	0.03 (0.01)	<0.001	293	0.03 (0.01)	<0.001	289	0.03 (0.01)	<0.001	281	0.02 (0.01)	<0.001
Hispanic	245	0.01 (0.01)	0.190	245	0.01 (0.01)	0.210	241	0.01 (0.01)	0.181	239	0.01 (0.01)	0.356
Chinese	123	0.03 (0.02)	0.117	123	0.02 (0.01)	0.108	121	0.02 (0.02)	0.114	117	0.02 (0.02)	0.255
<i>P_{interaction} (race*age*WC)</i>			<i>0.071</i>			<i>0.157</i>			<i>0.110</i>			<i>0.135</i>

Abbreviations: AHI, apnea-hypopnea index; BMI, body mass index; PA, physical activity; SE, standard error; WC, waist circumference.

^a Adjusted for age, sex, and study site (except for stratified analysis by sex and age groups).

^b Adjusted for age, sex, study site, smoking, and physical activity (except for stratified analysis by sex and age groups).

^c Adjusted for age, sex, race (except for stratified analysis), income, educational attainment, hypertension, diabetes, smoking status, physical activity, and study site.

In all models, the outcome variable apnea-hyponea index (AHI) was with natural log transformation. As some confounders had missing data, the summed numbers for adjusted models might not be equal to the numbers as shown for unadjusted models.

The beta estimate reflecting increase in the log-transformed AHI corresponded to one unit increase in waist circumference.