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Association of adiposity with pulmonary function in older Chinese: Guangzhou Biobank Cohort Study

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Abstract

Objective We examined the association between different adiposity indices and pulmonary function in Chinese adults in the Guangzhou Biobank Cohort Study (GBCS).

Methods Participants with body mass index (BMI) <18.5 (underweight) were excluded. Adiposity indices including BMI, waist circumference (WC), waist hip ratio, waist height ratio and body fat percentage were measured. Lung function was assessed by spirometry using a turbine flowmeter. We analyzed percent predicted for forced expiratory volume in 1 second (FEV_1%), forced vital capacity (FVC %) and restrictive respiratory defect (FEV_1 /FVC ratio >low limits of normal and FVC % <0.80).

Results Of 16186 participants (mean age 61.4±7.2 years; 74.0% women), 116 (0.7%) had general obesity only (BMI ⩾28 kg/m^2), 4079 (25.2%) had central obesity only (WC: ⩾90 cm in men, ⩾80 cm in women) and 1591 (9.8%) had both central obesity and general obesity. Comparing to those with neither central nor general obesity, those with central adiposity only and with both central and general obesity had lower pulmonary function (adjusted β range from -2.85 to -6.02 for FEV_1% and FVC%, adjusted OR range from 1.14 to 1.70, all P <0.05). But those with general obesity only had better but non-significant pulmonary function. (Crude β range from 1.46 to 2.92 for FEV_1% and FVC%, crude OR range from 0.68 to 0.93, all P >0.05). Both FEV_1% and FVC% decreased per standard deviation increase in obesity indices (adjusted β from -0.46 to -3.17, all P <0.002). A positive association of central or general obesity with restrictive respiratory defect was observed (adjusted odds ratio (AOR) from 1.50 to 2.04, all P <0.002). Further adjustment for WC reversed the inverse association between BMI and pulmonary function (adjusted β from 1.93 to 6.22, all P <0.001) and restrictive respiratory defect (adjusted AOR from 0.72 to 0.80, all P <0.001).

Conclusion: Central adiposity and its indices, but not general adiposity and BMI, were independently associated with lower pulmonary function and higher risk of restrictive respiratory defect in older Chinese. (331 words)

Keywords

Pulmonary function, restrictive respiratory defect, central adiposity, general adiposity, WC,

BMI

Introduction

The prevalence of obesity has been rising rapidly over the past decade to become a worldwide disease burden [1]. Obesity is well recognized as a risk factors for type 2 diabetes, cardiovascular diseases [2] and cancers [3]. Poor pulmonary function (low forced expiratory volume in 1 second (FEV_1)) is an important long-term predictor of mortality in the general population [4] and in particular a marker for cardiovascular mortality[5]. While body mass index (BMI) is the most widely used general adiposity measure[6], indices of central adiposity may be better predictors for future cardiovascular risk [7, 8].

Many studies have explored the relationship between adiposity indices and lung function, with most [9-14], but not all [15] of these studies showing an inverse association of pulmonary function with central obesity and its indices. While some studies showing an inverse association[9, 11, 12] and others showing a weak or non-significant association [15-17] of pulmonary function with BMI and general obesity. Interaction by sex and smoking were seldom tested in previous studies[9]. The few studies that have examined the influences of different obesity indices on lung function were mainly based on Western populations[11, 12], while Asians have a more central distribution of adipose tissue than Caucasians at the same BMI[18].We found only one study on 770 participants reporting forced vital capacity (FVC) %, but not FEV_1, was lower in overweight subjects instead of general obesity subjects in Xi'an[19]. Few papers explored which adiposity indices were independently associated with pulmonary function, only two papers adjusted BMI in analyzing the associations between central obesity indices and pulmonary function[11, 14], one of them indicating that adjustments strengthened the inverse association[14].

Hence, we analyzed the baseline data from the Guangzhou Biobank Cohort Study (GBCS) to further explore the association of different adiposity indices and pulmonary function.

Methods

Study participants

Guangzhou Biobank Cohort Study (GBCS) is a three-way collaboration among the Guangzhou Number 12 Hospital, the Universities of Hong Kong and Birmingham. A total of 30430 older Chinese (aged 50 years or over) in Guangzhou were recruited at baseline from 2003 to 2008, and details have been reported [20]. The Guangzhou Medical Ethics Committee of the Chinese Medical Association approved the study and all participants gave written informed consent before participation.

Briefly, trained interviewers used a standardized computer-based questionnaire to collect information on the demographic characteristics, family and personal disease history and lifestyle, including smoking and alcohol drinking. The Chinese version of the International Physical Activity Questionnaire (IPAQ-C) which was validated by us was used for assessing physical activity [21]. IPAQ data were converted to metabolic equivalent scores for each type of activity, and were categorized to 3 groups of low, moderate and high levels of activity.

Body weight and height were measured using standardized protocols and instruments, height in bare feet was measured to the nearest 0.5 cm using a Holtain stadiometer and weight in light clothes using standardized scales to the nearest 0.5 kilogram using a weighing apparatus (RGZ-120-RT, Wuxi weighing apparatus factory, Wuxi, China). by trained researchers [20]. BMI was calculated as weight divided by square of the height (kg/m^2). General obesity was defined using a BMI cut-off point $\geq$28 kg/m^2, based on the criteria of the National Health and Family Planning Commission of the People's Republic of China [22], with BMI

18.5-23.9 kg/m^2 classified as healthy weight and 24-27.9 kg/m^2 as Overweight. We did not include participants whose BMI <18.5 (underweight) in our study because the mechanism for pulmonary function in those participants would be different from that in other BMI groups.

Waist circumferences (WC) was taken as the minimum circumference between the umbilicus and xiphoid process, and central obesity was defined by WC $\geqslant$90 cm in men and $\geqslant$80 cm in women [23]. Hip circumference was measured as the maximum circumference around the buttocks and the symphysis pubis. Waist hip ratio (WHR) was calculated as WC divided by hip circumference. Waist height ratio (WHtR) was calculated as WC divided by height. Body fat percentage was measured using a bioelectrical impedance analyzer analyzer (Tanita BF350, Tanita Inc., Japan). These data had been used in several GBCS papers[24, 25].

For comparison, obesity indices were standardized using Z score transformation to analyze the association with pulmonary function. The standard deviation (SD) of BMI, WC, WHR, WHtR and body fat percentage was 3.3kg/m^2, 9.0 cm, 7%, 6% and 8% in whole study, respectively. Sex specific SDs were used in different sex group.

Spirometry was done with a pneumotachograph (Chestgraph HI-701, Chest MI Inc, Tokyo, Japan) in phase I and a turbine flowmeter (Cosmed microQuark, Rome, Italy) in phase II and two ultrasonic flowmeters (ndd Medical Technologies Easy-on PC; Zurich, Switzerland) in phase Ⅲ. Details of the methods have been reported elsewhere [26, 27]. Briefly, the pulmonary function test was conducted in a standing position following standard procedures, and at least three maneuvers and the best measure of FEV_1 and FVC were recorded. Predicted values for FEV_1 and FVC were derived using the equations developed by Ip and colleagues for Chinese [28]. The outcome variables were (1) FEV_1 % predicted (FEV_1 %),(2) FVC % predicted (FVC %) and (3) restrictive respiratory defect (FEV_1 /FVC ratio $\geqslant$lower limits of normal (LLN) and FVC% <0.80)[29].

Statistical analysis

Continuous variables were analyzed using independent sample t-test and categorical variables using χ^2 test. Regression model was used to assess the association between FEV_1%, FVC% and presence of restrictive respiratory defect in different BMI groups and obesity type (normal, with general obesity only, with central obesity only and with both general and central obesity). The linearity of the association between adiposity measures and pulmonary function was examined using margins, with marginal linear prediction plotted on the **y**-axis and WC/BMI as a continuous variable on the **x**-axis. The results showed no evidence for the non-linearity for both BMI and WC (Figures not shown), supporting the use of multiple linear regression to calculate regression coefficient (β) and 95% confidence interval (CI) for the association between different obesity status and adiposity indices (continuous variables) and pulmonary function measurements with adjustment for age, height, education (≤primary, middle school and ≥college), smoking (never, former and current smokers), occupation (manual, non-manual and others), physical activity (low, moderate and high level), airflow obstruction, self-reported asthma and wheezing as appropriate. Multivariable logistic regression was used to calculate the odds ratio (OR) of the presence of restrictive respiratory defect according to central and general obesity (as dichotomous variables) and obesity indices with adjustment for the same confounders above. WC was further adjusted in the regression model of general obesity and BMI and pulmonary function, while BMI further adjusted in the model of central obesity and WC and pulmonary function. To detect the existence of potential multicollinearity, we calculated variance inflation factors (VIF) for linear regression models to quantify how much the variance was inflated. A VIF value of less than 2 usually means multicollinearity is ignorable[30]. For all models including both BMI and WC, all VIFs were less than 2.0, indicating the problem of multicollinearity might not be a major concern. Moreover, the mutual adjustment of BMI and WC was done to assess the independent association of these adiposity measures with pulmonary function, and this method has been used by many other studies to assess their independent associations with other health conditions or mortality[31-34].

We tested for interaction between obesity and sex using likelihood ratio test for the fitness of models with or without the interaction terms. Models with a lower Akaike information criterion (AIC) value indicate better fitness. As there was evidence for sex interaction for the association between adiposity measures and pulmonary function, and body composition as well as lung volumes vary largely between men and women, all analyses were performed stratified by sex. All tests of significance were 2-tailed, with $P < 0.05$ as statistically significant. All analyses were performed using Stata / SE 12.0 (StataCorp LP, 4905 Lakeway Drive, College Station, TX77845 USA).

Results

Of 30430 participants in GBCS study, after excluding those with BMI <18.5 (underweight), 16186 (53.2%) with valid data were included in this analysis [7]. The mean (± standard deviation) age was 61.4±7.2 years and most of them were women (74.0%). 116 (0.7%) participants were defined as having general obesity only, 4079 (25.2%) central obesity only, and 1591 (9.8%) having both central and general obesity. Table 1 shows that compared with those without, a higher proportion of those with central obesity were women and older, had lower socioeconomic position (lower education and more manual occupation), lower lung function, higher prevalence of restrictive respiratory defect and self reported wheezing, and were non-smokers.

Table 2 shows that those with overweight and general obesity, as assessed by BMI, had lower

FVC% than those with normal weight (β from -1.45 to -4.85, all P <0.01). FEV_1% was lower in women who were obese (β -3.70, 95% CI -4.73 to -2.66), but not in those who were overweight (all p >0.05). The prevalence of restrictive respiratory defect was higher in those with overweight and general obesity (OR from -1.19 to -1.74, all P <0.01). Further adjusted for age, height, education, smoking, occupation, physical activity, airflow obstruction, self-reported asthma and wheezing did not change the results substantially, only the FEV_1% became significantly lower in men with overweight and obesity (adjusted β -1.66 and -3.11, all P <0.01).

Table 3 shows that those who had central obesity only and who had both central and general obesity had lower FEV_1% and FVC% (β from -2.54 to -7.36, all P <0.01) and higher prevalence of restrictive respiratory defect (OR from -1.76 to -2.23, all P <0.01) than those with normal weight. Differences between those who had general obesity only and those without neither central nor general obesity were non-significant (all P >0.05). Further adjustment for the same confounders did not change the results substantially.

Table 4 shows that after adjusting for confounders above, central obesity and its indices Z score (WC, WHtR, WHR and body fat) were significantly inversely associated with FVC% and FEV_1% (adjusted β from -1.27 to -5.39, all P <0.001), and higher risk of restrictive respiratory defect (AOR from1.17 to 2.04, all P <0.001). The inverse associations between general obesity and BMI Z score and FVC% and FEV_1% were weaker than that of central obesity indices (adjusted β from -0.46 and -3.46, all P <0.001). Further adjustment of BMI strengthened the association between WC and FEV_1% and FVC% (adjusted β -4.09 and -7.77, all P <0.001). After further adjustment of WC, BMI Z score became positively associated with FEV_1% and FVC% (adjusted β from 1.93 to 6.22, P <0.001) and restrictive respiratory defect (AOR from 0.72 to 0.80, all P <0.001).

Table 4 also shows that the negative associations of obesity with lower FEV_1, FVC and higher risk of restrictive respiratory defect were stronger in men than in women. After adjusting for WC, the positive association between BMI and pulmonary function was stronger in men than in women (most P values for sex interaction <0.05). But the associations of general obesity, WC, weight hip ratio, weight height ratio and body fat percentage with poorer pulmonary function did not vary by sex (P for sex interaction >0.05). As very few women (<2%) smoked in China, the interaction test between smoking and adiposity was conducted in men only (data not shown). We found no evidence that the association of pulmonary function with obesity varied by smoking status (most P for smoking interaction ranged from 0.11 to 0.80).

Discussion

Our study of older Chinese in Southern China showed that those with central obesity and those with both central and general obesity, but not those with general obesity only, had lower pulmonary function. We also found all obesity status and indices were associated with lower FEV_1 and FVC (except BMI was not significantly associated with FEV_1 in men) and higher presence of restrictive respiratory defect. Further adjustment of WC reversed the relationship between BMI with lung function substantially. Our results suggest that central obesity and its indices, rather than general obesity and BMI, are associated with poor lung function. The relationships stated above were similar in both gender and irrespective of smoking status.

Previous studies showed that both central and general obesity were negatively associated with pulmonary function, but WC had better explanatory power than BMI [9]. Evidence on the association between BMI and FEV_1 and FVC was complex and the results were inconclusive [9, 16, 35, 36], with one study reporting an inverted U-shaped relationship [35], some reporting a negative [9] or no [16, 36] and even positive [16, 36] associations, but none of them had further adjusted WC to clarify. On the other hand, some studies adjusted for BMI in exploring the relationships between central obesity indices and pulmonary function [11, 14], with one study showing that this strengthened the association between WC and pulmonary function [14]. One possible explanation for the positive association between BMI and pulmonary function could be due to reverse causation: people with chronic lung disease or poor lung function tended to lose muscle mass, and that leads to lower BMI. But lack of exercise due to the poor lung function can lead to high waist circumference. The mechanism by which central obesity may influence pulmonary function is different from that of general obesity. Central obesity may restrict the diaphragm movement and limit lung expansion while general obesity may compress the chest wall [37]. A reduction in the functional residual capacity due to mass load of adipose tissue around the rib cage and abdomen and in the visceral cavity might be one of the main mechanisms[38]. A systematic review showed that WC tends to be inversely associated with FEV_1 and FVC [10].Although accepted worldwide as an important index for defining obesity, BMI cannot distinguish between the fat mass and fat free mass, and compartments of body composition including fat, bone, water and muscle. Several studies suggested that the fat distribution and fat mass amount have distinct effects on pulmonary function [39, 40]. The association of obesity with pulmonary function might be affected by the distribution of body fat [10], and central obesity was associated with respiratory mechanics regardless of BMI [11, 41].

Our findings are broadly consistent with previous studies in the general population that reported a negative association between central and general adiposity and pulmonary function. The European Prospective Investigation into Cancer and Nutrition-Norfolk (EPIC-Norfolk) study found an inverse linear association of WHR with pulmonary function, and showed that the association remained significant in subjects without smoking and/or obesity [14]. The

EPIC-Norfolk study suggested that WHR might be a better indicator than BMI in assessing the role of adiposity in predicting lung function in the general population. Few studies adjusted WC for general obesity or BMI for central obesity. However, in our study with a larger number of participants, all central obesity indices showed significantly association with poorer pulmonary function (lower FEV_1 and FVC and higher risk of restrictive respiratory defect), which remained with further adjustment of BMI.

Consistent with previous studies [9], We also found that the associations of adiposity indices with pulmonary function were stronger in men than in women (P for sex interaction from <0.001 to 0.35 for FVC), which may reflect gender differences in body fat distribution. Men have greater lean mass but less fat mass than women, but their fat mass tends to accumulate around the abdomen, while females deposit fat predominantly around the hips [42]. It is likely that visceral fat volume, rather than fat proportions, affects the reduction of diaphragmatic movement and chest-wall expansion [38]. As smoking is a major risk factors for poor pulmonary function, but smokers tend to have a lower BMI and higher WHR [43], the role of smoking in this association should be examined with caution. Our findings showed that the association of adiposity with pulmonary function was independent of smoking.

There were several strengths in our study. First, we excluded participants with under-weight as they could have underlying diseases and the mechanisms and relationships for lung function could be different and complex. Pooling them together with normal weight people as a reference group could lead to unclear results, but only a few studies did exclude them [9, 17, 36, 44]. Second, as adiposity indices were measured more comprehensively, we could explore the association of different adiposity indices with pulmonary function. Third, BMI and WC were mutually adjusted, which were seldom conducted in previous studies, to clarify the independent effects of different adiposity indices on lung function. Fourth, the large sample size and detailed assessment of potential confounders as well as effect modifiers also facilitate our demonstration of the independent effect of central obesity on pulmonary function.

However, there were also some limitations. First, a causal inference could not be confirmed in the current cross-sectional study. Second, our sample size might not be enough to detect small but important interaction effects and much larger studies are needed. Third, we cannot completely rule out the possibility of reverse causality, which means that the higher levels of adiposity could be the result of reduction in physical activity due to poor pulmonary function. However, we adjusted for physical activity and the results of a sensitivity analysis examining the association in those with good and bad self-reported health were similar. Fourth, the sample size of participants with only general obesity was much less than that of participants with only central obesity and with both general and central obesity, that might lead to insufficient power to detect the significance of the difference.

In conclusion, we found that central adiposity and its indices, but not general adiposity and BMI, were independently associated with lower pulmonary function and higher risk of restrictive respiratory defect in older Chinese. BMI was even positively associated with pulmonary function after controlling of WC. The association did not vary by sex or smoking status, though the negative associations of central obesity with lower pulmonary function were stronger in men. Previous observations on BMI might be inadequate and the relationships between BMI and pulmonary function might be confounded or mediated partly by WC, or confused by including pooling under-weight and normal weight subjects as a reference. Hence future studies should examine central obesity and accounting for general obesity. To maintain better pulmonary function in older Chinese with higher prevalence of central obesity, we might pay more attentions to controlling WC and central adiposity instead of BMI and general adiposity.

Conflict of interest statement: We declare no conflict of interests.

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Table 1. Demographic characteristics and clinical parameters by central obesity status (N=16186)

	Men			Women		
	Normal WC	Central obesity	P-values	Normal WC	Central obesity	P-values
Number	3366	837		7150	4833	
Men, n (%)						
Age, y, mean±SD	63.8±6.8	64.7±7.0	<0.001	59.4±7.0	62.1±7.1	<0.001
Education, n (%)			0.54			<0.001
≤Primary	959 (28.5)	242 (28.9)		2703 (37.8)	2736 (56.6)	
Middle school	1851 (55.0)	445 (53.2)		3969 (55.5)	1862 (38.5)	
≥College	556 (16.5)	150 (17.9)		478 (6.7)	235 (4.9)	
Smoking, n (%)			<0.001			<0.001
Never	1289 (38.3)	324 (38.7)		6961 (97.4)	4640 (96.0)	
Former	943 (28.0)	289 (34.5)		84 (1.2)	101 (2.1)	
Current	1134 (33.7)	224 (26.8)		105 (1.5)	92 (1.9)	
IPAQ Physical activity, n (%)			0.92			0.01
Low	281 (8.4)	71 (8.5)		633 (8.9)	381 (7.9)	
Moderate	1426 (42.4)	360 (43.0)		2568 (35.9)	1851 (38.3)	
High	1659 (49.3)	406 (48.5)		3949 (55.2)	2601 (53.8)	
Occupation, n (%)			0.91			<0.001
Manual	1246 (37.0)	313 (37.4)		3010 (42.1)	2496 (51.6)	
Non-manual	1458 (43.3)	365 (43.6)		2450 (34.3)	1464 (37.4)	
Others	662 (19.7)	159 (19.0)		1690 (23.6)	873 (18.1)	
Airway Obstruction, n (%)	200 (5.9)	34 (4.1)	0.03	363 (5.1)	258 (5.3)	0.53
Self-reported wheezing, n (%)	140 (4.2)	46 (5.5)	0.10	123 (1.7)	183 (3.8)	<0.001
Self-reported asthma, n (%)	52 (1.9)	16 (2.3)	0.48	82 (1.3)	83 (2.0)	0.01
Height, cm, mean±SD	164.0±5.8	166.3±6.2	<0.001	153.5±5.3	154.1±5.5	<0.001
Body mass index, kg/m^2, mean±SD	23.0±2.3	27.5±2.4	<0.001	22.6±2.2	26.5±2.8	<0.001
WC, cm, mean±SD	79.6±6.2	94.6±4.7	<0.001	72.6±4.6	86.2±5.5	<0.001
Waist/hip ratio, mean±SD	0.89±0.05	0.97±0.04	<0.001	0.82±0.05	0.90±0.06	<0.001
Waist/height ratio, mean±SD	0.49±0.04	0.57±0.03	<0.001	0.47±0.03	0.56±0.04	<0.001
Body fat†, %, mean±SD	22.3±5.0	29.1±4.7	<0.001	31.0±5.5	38.7±6.4	<0.001
Restrictive respiratory defect, n (%)	654 (20.7)	280 (34.9)	<0.001	1026 (15.1)	1151 (25.2)	<0.001
FEV_1, L, mean±SD	2.32±0.58	2.24±0.57	0.001	1.84±0.40	1.72±0.41	<0.001
FEV_1 %, %, mean±SD	92.1±18.9	86.8±21.0	<0.001	96.9±17.2	92.3±18.0	<0.001
FVC, L, mean±SD	3.00±0.66	2.88±0.64	<0.001	2.29±0.48	2.14±0.48	<0.001
FVC %, %, mean±SD	91.8±16.7	85.4±19.2	<0.001	95.0±16.3	89.3±16.2	<0.001
FEV_1/FVC, %, mean±SD	77.1±8.8	77.5±8.3	0.21	80.1±6.5	80.3±7.2	0.19

WC, waist circumference; IPAQ, International Physical Activity Questionnaire; FEV_1,

forced expiratory volume in 1 second; FEV_1 %, forced expiratory volume in 1 second % predicted; FVC, forced vital capacity; FVC %, forced vital capacity % predicted;
Central obesity: waist circumference ≥90 cm in men or ≥80 cm in women.
Airway obstruction: FEV_1 /FVC ratio <lower limits of normal (LLN) without self-reported asthma.
Restrictive respiratory defect: FEV_1 /FVC ratio ≥LLN and FVC % <0.80.
[†]: n=6397, missing values were excluded here only.

Table 2. Association (regression coefficient β/ odd ratio, 95% confidence interval (CI)) of different BMI groups with Pulmonary function (N=16186)

	N	FEV_1%, %		FVC %, %		Restrictive respiratory defect[$]	
		Crude β (95% CI)	Adjusted β (95% CI)	Crude β (95% CI)	Adjusted β (95% CI)	Crude OR (95% CI)	Adjusted OR (95 CI)
Men							
Normal	2280	0.00	0.00	0.00	0.00	1.00	1.00
Overweight	1571	0.11 (-1.14 to 1.36)	-1.66 (-2.89 to -0.44)	-1.90 (-3.01 to -0.78)	-2.74 (-3.92 to -1.56)	1.42 (1.21 to 1.66)	1.58 (1.32 to 1.90)
Obesity	352	-1.01 (-3.20 to 1.17)	-3.11 (-5.19 to -1.04)	-3.32 (-5.27 to -1.37)	-4.13 (-6.14 to -2.12)	1.68 (1.30 to 2.17)	1.89 (1.42 to 2.53)
P-value		0.70	<0.001	<0.001	<0.001	<0.001	<0.001
Women							
Normal	6202	0.00	0.00	0.00	0.00	1.00	1.00
Overweight	4426	-0.38 (-1.06 to 0.30)	-0.45 (-1.13 to 0.22)	-1.45 (-2.08 to -0.81)	-1.20 (-1.85 to -0.55)	1.19 (1.07 to 1.31)	1.16 (1.04 to 1.30)
Obesity	1355	-3.70 (-4.73 to -2.66)	-3.10 (-4.13 to -2.07)	-4.85 (-5.81 to -3.88)	-3.97 (-4.96 to -2.98)	1.74 (1.51 to 2.01)	1.60 (1.37 to 1.87)
P-value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

BMI: body mass index; FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; CI: confidence interval; OR: odd ratio;

Restrictive respiratory defect: FEV_1 /FVC ratio ≥lower limits of normal and FVC % <0.80

Normal: 18.5 ≤BMI < 24 kg/m^2; Overweight: 24 ≤BMI < 28 kg/m^2; Obesity: BMI ≥28 kg/m^2;

Adjustment include age, height, education, smoking, occupation, physical activity, airflow obstruction, self-reported asthma and wheezing as appropriate

Table 3. Association of different obesity status with Pulmonary function (N=16186)

	N	FEV_1%, %		FVC %, %		Restrictive respiratory defect	
		Crude β (95% CI)	Adjusted β (95% CI)	Crude β (95% CI)	Adjusted β (95% CI)	Crude OR (95% CI)	Adjusted OR (9 CI)
Men							
Normal	3319	0.00	0.00	0.00	0.00	1.00	1.00
General obesity only	47	1.46 (-4.10 to 7.02)	-2.24 (-7.73 to 3.25)	1.98 (-2.97 to 6.94)	-0.69 (-6.00 to 4.63)	0.93 (0.45 to 1.94)	1.12 (0.48 to 2.62
Central obesity only	532	-6.87 (-8.63 to -5.10)	-5.86 (-7.64 to -4.08)	-7.36 (-8.93 to -5.78)	-6.20 (-7.92 to -4.48)	2.23 (1.82 to 2.72)	1.70 (1.29 to 2.24
General and central obesity	305	-2.54 (-4.81 to -0.28)	-3.31 (-5.44 to -1.17)	-4.42 (-6.44 to -2.40)	-4.20 (-6.27 to -2.14)	1.76 (1.37 to 2.30)	1.42 (1.03 to 1.95
P-value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Women							
Normal	7081	0.00	0.00	0.00	0.00	1.00	1.00
General obesity only	69	2.82 (-1.32 to 6.97)	2.45 (-1.61 to 6.51)	2.92 (-0.930 to 6.77)	1.89 (-2.00 to 5.78)	0.68 (0.31 to 1.48)	1.03 (0.46 to 2.31
Central obesity only	3547	-4.27 (-4.98 to -3.57)	-2.85 (-3.58 to -2.13)	-5.59 (-6.25 to -4.94)	-3.53 (-4.23 to -2.83)	1.80 (1.63 to 2.00)	1.14 (0.99 to 1.31
General and central obesity	1286	-5.38 (-6.42 to -4.34)	-4.27 (-5.32 to -3.23)	-6.60 (-7.56 to -5.63)	-5.07 (-6.07 to -4.07)	2.11 (1.83 to 2.43)	1.41 (1.18 to 1.68
P-value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

FEV_1 %, forced expiratory volume in 1 second % predicted; FVC %, forced vital capacity % predicted; CI: confidence interval; OR: odd ratio;

Restrictive respiratory defect: FEV_1 /FVC ratio ⩾lower limits of normal and FVC observed to predicted ratio <0.80.

General obesity: BMI ⩾28 kg/m^2

Central obesity: waist circumference ⩾90 cm in men or ⩾80 cm in women

Adjustment include age, height, education, smoking, occupation, physical activity, airflow obstruction, self-reported asthma and wheezing as appropriate

Table 4. Association (adjusted regression coefficient β/odd ratio, 95% confidence interval (CI)) of obesity indices with pulmonary function in all participants see above and by sex

	Men		Women	
	β (95% CI)	P	β (95% CI)	P
FEV_1%, %				
Central obesity	-4.82 (-6.26 to -3.37)	<0.001	-3.26 (-3.92 to -2.60)	<0.001
General obesity	-2.40 (-4.40 to -0.39)	0.02	-2.91 (-3.90 to -1.92)	<0.001
WC, SD	-2.60 (-3.23 to -1.97)	<0.001	-2.22 (-2.58 to -1.86)	<0.001
WC, SD*	-7.66 (-8.81 to -6.51)	<0.001	-4.09 (-4.67 to -3.52)	<0.001
BMI, SD	-0.46 (-1.11 to 0.20)	0.17	-0.78 (-1.11 to -0.44)	<0.001
BMI, SD[#]	6.22 (-5.03 to 7.41)	<0.001	2.24 (1.70 to 2.77)	<0.001
WHR, SD	-2.86 (-3.52 to -2.20)	<0.001	-2.16 (-2.51 to -1.82)	<0.001
WHtR, SD	-2.51 (-3.16 to -1.86)	<0.001	-2.15 (-2.50 to -1.81)	<0.001
Body fat %, SD[†]	-1.48 (-2.88 to -0.09)	0.04	-1.27 (-1.81 to -0.73)	<0.001
FVC%, %				
Central obesity	-5.39 (-6.79 to -4.00)	<0.001	-3.97 (-4.60 to -3.33)	<0.001
General obesity	-2.95 (-4.90 to -1.01)	0.003	-3.46 (-4.40 to -2.51)	<0.001
WC, SD	-3.17 (-3.78 to -2.57)	<0.001	-2.67 (-3.01 to -2.33)	<0.001
WC, SD*	-7.77 (-8.87 to -6.66)	<0.001	-4.29 (-4.84 to -3.74)	<0.001
BMI, SD	-1.12 (-1.76 to -0.48)	0.001	-1.22 (-1.55 to -0.90)	<0.001
BMI, SD[#]	5.65 (4.50 to 6.80)	<0.001	1.93 (1.42 to 2.45)	<0.001
WHR, SD	-3.15 (-3.78 to -2.51)	<0.001	-2.45 (-2.78 to -2.11)	<0.001
WHtR, SD	-3.09 (-3.72 to -2.46)	<0.001	-2.60 (-2.93 to -2.26)	<0.001
Body fat %, SD[†]	-2.29 (-3.64 to -0.95)	0.001	-1.82 (-2.32 to -1.32)	<0.001
Presence of restrictive respiratory defect	Odds ratio (95% CI)	P	Odds ratio (95% CI)	P
Central obesity	2.04 (1.67 to 2.49)	<0.001	1.53 (1.38 to 1.71)	<0.001
General obesity	1.53 (1.16 to 2.02)	0.002	1.50 (1.29 to 1.74)	<0.001
WC, SD	1.53 (1.39 to 1.68)	<0.001	1.35 (1.27 to 1.43)	<0.001
WC, SD*	2.02 (1.67 to 2.43)	<0.001	1.62 (1.48 to1.78)	<0.001
BMI, SD	1.31 (1.19 to 1.44)	<0.001	1.15 (1.09 to 1.21)	<0.001
BMI, SD[#]	0.72 (0.59 to 0.87)	0.001	0.80 (0.73 to 0.88)	<0.001
WHR, SD	1.43 (1.29 to 1.58)	<0.001	1.31 (1.24 to 1.39)	<0.001
WHtR, SD	1.54 (1.39 to 1.70)	<0.001	1.34 (1.26 to 1.42)	<0.001
Body fat %, SD[†]	1.55 (1.23 to 1.95)	<0.001	1.17 (1.05 to 1.31)	0.006

FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; WC, waist circumference; BMI, body mass index; WHR, waist hip ratio; WHtR, waist height ratio;

General obesity: BMI ⩾28 kg/m^2

Central obesity: waist circumference ⩾90 cm in men or ⩾80 cm in women

Restrictive respiratory defect: FEV1/FVC ratio ⩾lower limits of normal and FVC % <0.80

1SD BMI =2.92 kg/m^2 in men, =3.12 kg/m^2 in women

1SD WC=8.43 cm in men, =8.30 cm in women

1SD WHR =6.0% in men, =6.4% in women
1SD WHtR=5.1% in men, =5.5% in women
1SD body fat %=5.6 % in men, =6.9 % in women
Adjustment include age, height, education, smoking, occupation, physical activity, airflow obstruction self-reported asthma and wheezing as appropriate.
*: further adjusted for BMI
#: further adjusted for WC
†: n=6397, missing values were excluded here only.