Waist circumference is associated with pulmonary function in normal-weight, overweight, and obese subjects[1–3]

Yue Chen, Donna Rennie, Yvon F Cormier, and James Dosman

ABSTRACT

Background: Obesity is becoming a serious public health issue and is related to lung dysfunction. Because both weight and height are indicators of body size, body mass index (BMI) may not be an ideal index of obesity in prediction of pulmonary dysfunction.

Objective: The objective of the study was to determine the predictability of waist circumference (WC) and BMI for pulmonary function in adults with and without excess body weight.

Design: A cross-sectional study of 1674 adults aged ≥18 y was conducted in a rural community. Height, weight, WC, and pulmonary function were measured. Multivariate analysis was conducted.

Results: WC was negatively associated with forced vital capacity and forced expiratory volume in 1 s, and the associations were consistent across sex, age, and BMI categories. On average, a 1-cm increase in WC was associated with a 13-mL reduction in forced vital capacity and an 11-mL reduction in forced expiratory volume in 1 s. The association between WC and pulmonary function was consistent in subjects with normal weight, overweight, and obesity. In subjects with normal weight, BMI was positively associated with forced vital capacity and forced expiratory volume in 1 s.

Conclusion: WC, but not BMI, is negatively and consistently associated with pulmonary function in normal-weight, overweight, and obese subjects. *Am J Clin Nutr* 2007;85:35–9.

KEY WORDS Adults, body mass index, lung, lung function, obesity, waist circumference

INTRODUCTION

Obesity is becoming a serious public health issue, especially in developed countries (1). A growing body of evidence indicates that obesity is associated with a wide range of health conditions, including respiratory diseases such as chronic obstructive pulmonary disease (COPD; 2) and asthma (3). Numerous studies have examined the association between body mass index (BMI; in kg/m^2) or weight change and pulmonary function testing variables, and the associations vary in different subpopulations (4–15).

Body weight and BMI can be easily measured and therefore are frequently used in large-scale epidemiologic studies. A major limitation of these measures is that they do not distinguish between fat mass and muscle (lean) mass, which have opposite effects on pulmonary function (7, 11, 16). Another important limitation is that both weight and height are surrogate measures of body size and are important predictors for pulmonary function measurements. A unit of body weight or BMI is likely to have less fat mass for underweight persons and for men than for overweight persons and for women (7). In addition, body weight and BMI provide no information on the nature of body fat distribution, both of which may play an important role on the association between obesity and pulmonary function (7).

Several studies have evaluated the relation of waist circumference (WC) and waist-to-hip ratio (WHR) to pulmonary function testing variables (14, 16–22). However, whether WC and BMI have a similar predictability for pulmonary function in nonobese and obese subjects is not known. This study aimed to determine the predictability of WC and BMI for pulmonary function in adults with and without excess body weight.

SUBJECTS AND METHODS

This analysis was based on data from a cross-sectional study conducted in the town of Humboldt, Saskatchewan, Canada, in 2003 (23). The target population was all residents of the town aged 18–79 y. Almost all of the study population was white. A total of 2057 adults—71% of the target population—participated in the study. The details of the study were given in a previous report (23).

Written informed consent was obtained from each participant. The study was approved by the University of Saskatchewan research ethics board.

Canvassers distributed a self-administered questionnaire to all eligible residents. Completed questionnaires were returned during a scheduled clinic visit. Collected information included demographic factors, education, occupation, income, smoking habits, coffee and alcohol consumption, respiratory symptoms, and illnesses. As defined previously (7, 23), current smokers were participants who reported smoking every day or almost every day

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TABLE 1
Anthropometric measures and pulmonary function by sex and age[1]

	n	Weight	BMI	WC	FVC	FEV_1	FEV_1:FVC
		kg	*kg/m²*	*cm*	*L*	*L*	*%*
Age (y)							
Men							
18–29	55	85.2 ± 15.6[2]	27.0 ± 5.4	92.5 ± 12.1	5.63 ± 0.73	4.60 ± 0.71	81.8 ± 8.0
30–39	134	90.6 ± 18.5	28.9 ± 5.7	97.5 ± 14.4	5.36 ± 0.87	4.31 ± 0.67	80.7 ± 6.4
40–49	168	92.2 ± 16.4	29.7 ± 4.9	100.3 ± 12.4	5.07 ± 0.76	4.11 ± 0.66	81.2 ± 7.1
50–59	140	91.1 ± 14.8	29.4 ± 4.3	101.4 ± 10.3	4.84 ± 0.80	3.84 ± 0.68	79.5 ± 7.0
60–69	127	89.6 ± 13.3	29.6 ± 3.9	103.1 ± 9.4	4.19 ± 0.71	3.28 ± 0.63	78.1 ± 6.4
70–79	114	87.2 ± 15.4	28.9 ± 4.9	104.0 ± 11.2	3.66 ± 0.75	2.76 ± 0.65	75.5 ± 9.2
Total	738	90.0 ± 15.9	29.1 ± 4.9	100.5 ± 12.1	4.75 ± 0.99	3.78 ± 0.87	79.4 ± 7.6
Women							
18–29	93	74.5 ± 18.3	27.1 ± 6.3	84.0 ± 13.9	4.15 ± 0.54	3.47 ± 0.49	84.8 ± 7.1
30–39	164	74.7 ± 17.4	27.4 ± 6.0	85.7 ± 13.5	3.98 ± 0.65	3.26 ± 0.52	82.3 ± 5.5
40–49	215	73.8 ± 15.1	27.7 ± 5.5	86.0 ± 12.9	3.72 ± 0.58	3.01 ± 0.48	80.9 ± 5.2
50–59	156	76.8 ± 16.7	29.6 ± 6.5	90.3 ± 14.5	3.27 ± 0.56	2.64 ± 0.48	80.9 ± 6.4
60–69	175	76.2 ± 16.4	29.4 ± 6.6	92.3 ± 14.4	2.96 ± 0.54	2.35 ± 0.47	79.2 ± 5.6
70–79	133	72.6 ± 14.9	28.4 ± 5.4	90.9 ± 13.9	2.58 ± 0.53	2.03 ± 0.45	78.5 ± 7.1
Total	936	74.8 ± 16.4	28.3 ± 6.1	88.3 ± 14.1	3.43 ± 0.77	2.78 ± 0.67	80.8 ± 6.2

[1] FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 s; WC, waist circumference; FEV_1:FVC, ratio of FEV_1 to FVC.
[2] All values are $\bar{x}$ ± SD.

and who had smoked ≥20 packs of cigarettes during their lifetime. Ex-smokers were those who had been regular smokers but who, at the time of the survey, had not smoked for ≥6 mo. Otherwise, subjects were defined as nonsmokers. Perceived level of physical activities was also recorded. Leisure-time physical activity was measured by asking the question: "Compared with the way other people your age now spend their spare time, would you say you are more physically active, equally physically active, or less physically active?"

During a clinical visit, lung function, height, weight, and WC were measured. Weight was measured to the nearest 0.1 kg. Height was measured (in cm) by using a fixed tape measure while participants stood, wearing no shoes, on a hard surface. WC was measured (in cm) horizontally through the narrowest part of the torso, between the lowest rib and the iliac crest (24).

A spirometer (MedGraphics CPF-S System; Medical Graphics Corporation, St Paul, MN) was used for pulmonary function testing. Two machines were calibrated every morning during the study period with the use of a standard syringe. Each subject was tested according to the American Thoracic Society criteria (25). Forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1), and the ratio of FEV_1 to FVC (FEV_1:FVC, in %) were included in this analysis. Values were corrected for body temperature, pressure, and saturation with water vapor.

We examined the association between WC, BMI, and pulmonary function testing variables by using multivariate multiple regression analysis (WC and BMI as continuous variables) or multivariate analysis of variance (MANOVA) (WC and BMI as categorical variables). For WC, 3 pulmonary function indexes were considered simultaneously, and adjustments were made for sex, age, standing height, body weight, and pack-years of smoking (1 pack-year = 20 cigarettes $\cdot$ d^{-1} $\cdot$ y^{-1}). Separate analyses were conducted for different BMI categories: normal weight, <25.0; overweight, 25.0–29.9; and obese, ≥30.0). Mean (95% CI) pulmonary function testing variables were calculated for subjects with low (<100 cm) and high (≥100 cm) WC after adjustment for height, weight, and pack-years of smoking. WC values >100 cm are most likely to be associated with potentially atherogenic metabolic disturbances in men and women (26). Similar analyses were performed for BMIs associated with the pulmonary function testing variables after adjustment for age and pack-years of smoking. Associations were considered to be significant if 2-sided P was < 0.05. All the analyses were conducted by using SPSS software (version 11.5; SPSS Inc, Chicago, IL).

RESULTS

The 1674 subjects (81.4% of the participants) who had satisfactory pulmonary function testing results and height, weight, and WC measures were included in this analysis. Of these 1674 subjects, 738 (45.1%) were men, and 936 (55.9%) were women. The mean (±SD) age was 51.0 ± 15.3 y for men and 50.4 ± 15.6 y for women. Of the study population, 35.0% were obese (BMI ≥30.0), a proportion that is higher than the Canadian national average (27), and 38.3% were overweight (BMI 25.0–29.9); 12.0% were current smokers, 33.8% were ex-smokers, and 54.2% were nonsmokers. The mean anthropometric measures and pulmonary function testing variables by sex and age groups are shown in **Table 1**.

WC was negatively associated with FVC and FEV_1 after adjustment for both standing height and body weight (**Table 2**). On average, a 1-cm increase in WC was associated with a 13-mL reduction in FVC and an 11-mL reduction in FEV_1 after adjustment for sex, age, height, weight, and pack-years of smoking. The association of WC with FEV_1:FVC was not significant (P = 0.212). The adjusted means for FVC and FEV_1 were significantly ($P < 0.001$) lower in subjects with a WC of ≥100 cm than in those with a WC of <100 cm (**Figure 1**).

The association of WC and BMI with pulmonary function testing variables by BMI category is shown in **Table 3**. WC was negatively associated with FVC and FEV_1, and the results were consistent across the age and BMI categories. The interaction of

TABLE 2
Association between waist circumference and pulmonary function adjusted for covariates[1]

	FVC (L)			FEV_1 (L)			FEV_1:FVC (%)		
	β	SE	*P*	β	SE	*P*	β	SE	*P*
WC (cm)	−0.013	0.002	< 0.001	−0.011	0.002	< 0.001	−0.031	0.025	0.212
Covariates									
Sex	0.681	0.043	< 0.001	0.575	0.038	< 0.001	0.785	0.489	0.108
Age (y)	−0.027	0.001	< 0.001	−0.026	0.001	< 0.001	−0.118	0.011	< 0.001
Height (cm)	0.058	0.002	0.011	0.038	0.002	< 0.001	−0.191	0.028	< 0.001
Weight (kg)	0.005	0.003	0.413	0.006	0.002	< 0.001	0.066	0.021	0.002
Smoking (pack-years)	−0.002	0.001	0.006	−0.004	0.001	< 0.001	−0.057	0.010	0.018

[1] $n = 1674$. β, regression coefficient for each predictor; FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 s; WC, waist circumference. Multivariate multiple regression analysis.

WC with BMI category was not significant for any of the pulmonary function testing variables. However, the association of BMI with pulmonary function was significantly modified by BMI category (Table 3). The associations of BMI with FVC and FEV_1 were negative and significant in overweight and obese subjects. In subjects with normal weight (BMI <25.0), however, BMI was positively associated with FVC ($P = 0.043$) and FEV_1 ($P = 0.02$). The pattern seen after further adjustment for height was similar.

DISCUSSION

Our data show that WC is significantly associated with FVC and FEV_1 but not with FEV_1:FVC. On average, a 1-cm increase in WC was associated a 13-mL reduction in FVC (15 mL for men and 11 mL for women) and an 11-mL reduction in FEV_1 (15 mL for men and 8 mL for women). The sex difference was not significant. These results are consistent with those from 2 previous epidemiologic studies. In a Scottish cross-sectional survey of 865 men and 971 women aged 25–64 y, Chen et al (18) found that WC was inversely associated with FVC (men: 8 mL/cm; women: 7 mL/cm) and FEV_1 (men: 17 mL/cm; women: 9 mL/cm). In a British cohort study of 9674 men and 11 876 women aged 45–79 y, Canoy et al (17) found significant relations of WHR with FVC and FEV_1 in both men and women. All of the above-mentioned associations persisted after adjustment for potential confounding factors. The current study also showed a tendency toward a stronger association between WC and FEV_1, which is in line with previous observations (14, 20, 22).

An important observation of the current study is that WC consistently had a negative association with the pulmonary function testing variables in all BMI categories, whereas BMI was positively associated with FVC and FEV_1 in normal-weight subjects. In a follow-up study of 3391 British subjects aged 18–73 y at baseline, Carey et al (14) found that the effect of weight gain on pulmonary function increased according to average weight at baseline.

For 2 major reasons, BMI is not an ideal measure for excess body weight as a predictor of pulmonary function. First, a higher BMI value for normal-weight persons than for obese persons may result from the fact that normal-weight persons have more muscle mass than fat mass. Second, BMI is calculated from body weight and height, which are correlated with body size—the larger the body size, the greater the pulmonary function testing variables. WC is also correlated with body size, but, when height and weight (which overall positively predicted pulmonary function testing variables) were included in the models, WC showed

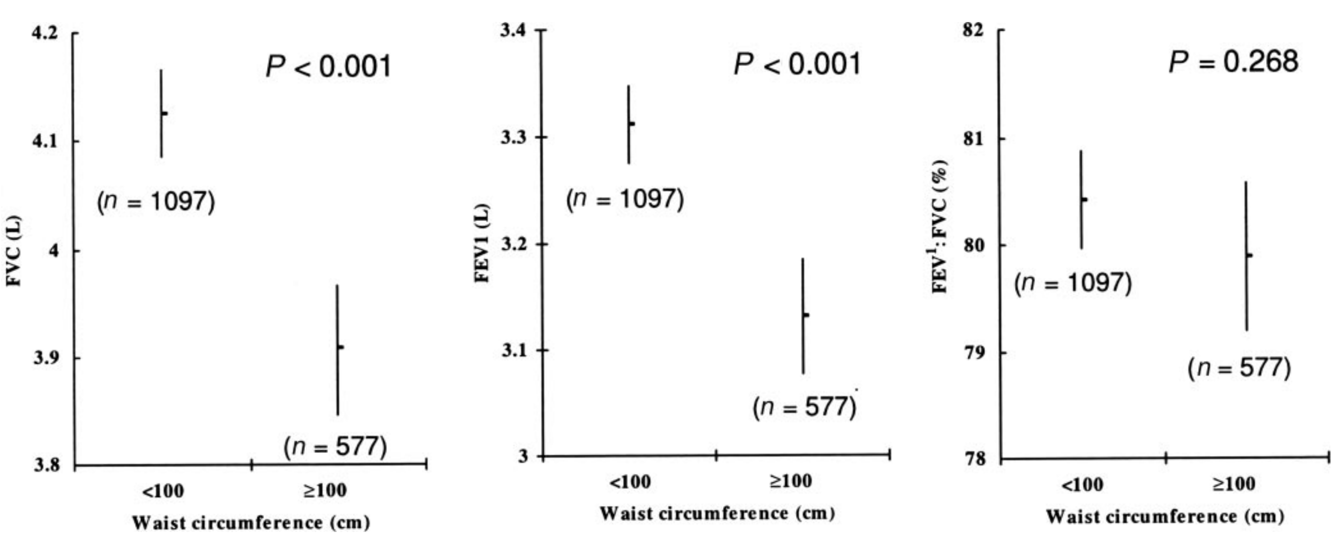

FIGURE 1. Adjusted mean (95% CI) pulmonary function testing variables by waist circumference in all subjects, obtained by multivariate ANOVA. FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 s.

TABLE 3
Associations of BMI and waist circumference (WC) with pulmonary function testing variables by BMI category[1]

	FVC (L)			FEV_1 (L)			FEV_1:FVC (%)		
	β	SE	*P*	β	SE	*P*	β	SE	*P*
BMI category									
WC (cm)[2]									
<25.0 (*n* = 447)	−0.011	0.005	0.026	−0.009	0.005	0.046	−0.011	0.067	0.865
25.0–29.9 (*n* = 641)	−0.015	0.004	< 0.001	−0.014	0.003	< 0.001	−0.055	0.040	0.165
≥30 (*n* = 586)	−0.013	0.003	< 0.001	−0.010	0.003	< 0.001	0.005	0.035	0.891
BMI (kg/m^2)[3]									
<25.0 (*n* = 447)	0.035	0.017	0.043	0.045	0.015	0.002	0.481	0.199	0.016
25.0–29.9 (*n* = 641)	−0.061	0.020	0.002	−0.038	0.017	0.023	0.252	0.176	0.153
≥30 (*n* = 586)	−0.023	0.006	< 0.001	−0.018	0.005	< 0.001	0.019	0.056	0.736

[1] β, regression coefficient for waist circumference; FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 s; FEV_1:FVC, ratio of FEV_1 to FVC. Multivariate multiple regression analysis.

[2] Adjusted for sex, age, pack-years of smoking, weight, and height. The interactions between WC and BMI category were not significant.

[3] Adjusted for sex, age, and pack-years of smoking. The interactions between WC and BMI category were significant: $P = 0.001$ for FVC, $P < 0.001$ for FEV_1, $P = 0.031$ for FEV_1:FVC.

a consistently negative association with pulmonary function across the BMI categories. Our results indicated that WC as a measure of abdominal fat deposition has a somewhat more consistent predictability for pulmonary function. A recent study found that WC was a better predictor of pulmonary function than was BMI, although the study did not examine the associations in different BMI categories (28). Another study found that BMI was negatively, not positively, associated with mortality in elderly persons after adjustment for WC, whereas WC was positively associated with mortality after adjustment for BMI (29). The results of that study also suggest that, in an elderly population, WC is a better indicator of adiposity than is BMI. A recent study found that total body fat and central adiposity were inversely associated with lung function in elderly (30).

Several studies used WHR as a predictor of pulmonary dysfunction (14, 17–20). Canoy et al (17) compared the relations of WC, WHR, and BMI with FVC and FEV_1 and found that pulmonary function was negatively associated with increasing quintiles of WHR, WC, and BMI, and, after adjustment for height, WHR in men and WC in women were associated with a bigger reduction in respiratory function than was BMI. Compared with WHR, WC is a more convenient measure, is less likely to be influenced by sex or degree of obesity (31), and is a better correlate with visceral adipose tissue (32). However, although these measures are convenient and can easily be applied in large-scale epidemiologic studies, they cannot separate out contributions of increased abdominal mass, restricted outward movement of the muscular abdominal wall, and intrathoracic factors. Magnetic resonance imaging (MRI) scanning, which can quantitate intra-abdominal fat, may validate these measures in future epidemiologic studies.

Obesity is likely a cause of pulmonary function decline. Respiratory function is determined by the interaction of lungs, chest wall, and muscles. Truncal obesity reduces chest wall compliance, respiratory muscle function, and peripheral airway size (33–36). Findings of reductions in functional residual capacity, expiratory reserve volume, and vital capacity, particularly in patients with severe obesity, are consistent (37). Whereas smoking has a larger effect on expired flow rates (as reflected by FEV_1) than on lung volume (as reflected by FVC), obesity affects lung volume to a larger degree than it affects expired flow rates. Our data showed that higher WC and BMI were associated with a significantly lower FVC, and consequently little effect on FEV_1:FVC was seen, which suggests that obesity has a primary effect on lung volume. The mechanical effects of the intraabdominal pressure on the diaphragm are likely the main reason for the association of central obesity with compromised lung function. Abdominoplasty improves pulmonary function in healthy subjects (38).

Explanations other than a detrimental effect of obesity on respiratory function are less likely. When we adjusted for exercise (perceived level of activity compared with their peers), the results remained the same. Because smoking is related to lower body weight and worse pulmonary function, it is not likely to be an explanation for the association of excess weight and pulmonary function. The possibility exists that subjects in a sitting posture take slightly smaller inspirations—and therefore have lower FVC and FEV_1 values—than do those in a standing posture (39). It is not known whether the comparative effects of sitting versus standing posture on the spirometric forced expiratory volumes are different in normal-weight, overweight, and obese subjects. However, even if those effects are different, those differences are unlikely to explain our results in the current study.

The clinical importance of the magnitude of association between WC and pulmonary function observed in the current study is not clear. However, numerous studies, including one from the same study population (23), have documented that abdominal obesity is associated with chronic respiratory disease.

In conclusion, our study found a consistent association between WC and pulmonary function in subjects with normal weight, overweight, and obesity. The negative association between BMI and pulmonary function was observed only in the overweight and obese. BMI was positively associated with FVC and FEV_1 in normal-weight subjects. Intraabdominal pressure that has a mechanical effect on the diaphragm is suspected of being a major reason for the association of obesity with lung dysfunction.

YC, DR, and JD contributed to the conception and design of the study; DR and JD supervised the data collection; YC performed the statistical analysis; YFC contributed to the explanation of the results; and all authors contributed

to the writing of the manuscript. None of the authors had a personal or financial conflict of interest with any aspect of this research.

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