Pulmonary Function and Abdominal Adiposity in the General Population*

Heather M. Ochs-Balcom, PhD; Brydon J.B. Grant, MD; Paola Muti, MD; Christopher T. Sempos, PhD; Jo L. Freudenheim, PhD; Maurizio Trevisan, MD; Patricia A. Cassano, PhD; Licia Iacoviello, PhD; and Holger J. Schünemann, MD, PhD

Background: **The prevalence of obesity is increasing, and there is evidence that obesity, in particular abdominal obesity as a marker of insulin resistance, is negatively associated with pulmonary function. The mechanism for this association and the best marker of abdominal adiposity in relation to pulmonary function is not known.**

Study objective: **We assessed the association between pulmonary function and weight, body mass index (BMI), waist circumference, waist/hip ratio, and abdominal height as markers of adiposity and body fat distribution. We used multiple linear regression to analyze the association of pulmonary function (*ie*, FEV_1 and FVC) [with maneuvers performed in the sitting position] with overall adiposity markers (*ie*, weight and BMI) and abdominal adiposity markers, stratified by gender, and adjusted for height, age, race, smoking, and other covariates.**

Setting and participants: **A random sample of individuals (n = 2,153) from the general population living in western New York state, 35 to 79 years of age.**

Results: **In women, abdominal height and waist circumference were negatively associated with FEV_1 percent predicted, while all five adiposity markers were negatively associated with FVC percent predicted. In men, all overall and abdominal adiposity markers were inversely associated with FEV_1 percent predicted and FVC percent predicted.**

Conclusion: **These results suggest that abdominal adiposity is a better predictor of pulmonary function than weight or BMI, and investigators should consider it when investigating the determinants of pulmonary function.** ***(CHEST 2006; 129:853–862)***

Key words: abdominal height; airway obstruction; body mass index; body weight; forced expiratory volume; FVC; obesity

Abbreviation: BMI = body mass index

Abdominal adiposity is a cardiovascular risk factor that is associated with insulin resistance, impaired glucose metabolism, hypertension, and dyslipidemia, all of which are features that are associated with the metabolic syndrome.[1,2] Insulin resistance is recognized as a low-grade inflammatory condition,[3,4] and proinflammatory cytokines (*ie*, adiponectin, leptin, tumor necrosis factor-α, and interleukin-6) are associated with adiposity.[5–9] Systemic inflammation is also thought to play a role[10,11] in the

*From the Department of Social and Preventive Medicine (Drs. Ochs-Balcom, Sempos, Freudenheim, and Trevisan), School of Public Health and Health Professions, University at Buffalo, Buffalo, NY; the Section of Pulmonary, Critical Care, and Sleep Medicine (Dr. Grant), Veterans Administration Center, Buffalo, NY; the Department of Epidemiology (Dr. Muti), Italian National Cancer Institute, Rome, Italy; the Department of Medicine (Dr. Schünemann), School of Medicine and Biomedical Sciences, University at Buffalo, Buffalo, NY; the Division of Nutritional Sciences (Dr. Cassano), Cornell University, Ithaca, NY; and the Center for High Technology Research and Education in Biomedical Sciences (Dr. Iacoviello), Catholic University, Campobosso, Italy.

Drs. Ochs-Balcom, Grant, Muti, Freudenheim, Trevisan, Cassano, and Schünemann disclose that they have received no financial support or had involvement with organizations with a financial interest in the subject matter of this study.

Manuscript received August 26, 2005; revision accepted December 25, 2005.

Correspondence to: Holger J. Schünemann, MD, PhD, INFORMA, National Cancer Institute Regina Elena, Rome, Via Elio Chianesi 53, 00144 Rome, Italy; e-mail: schuneh@mcmaster.ca

association between reduced pulmonary function and cardiovascular mortality as well as all-cause mortality.[12,13] However, the exact mechanism for the latter association is not fully understood. Insulin resistance and inflammation that arise from abdominal adiposity may mediate the relation of pulmonary function and all-cause mortality.

Weight and body mass index (BMI) as measures of overall adiposity are used as predictors of pulmonary function in many epidemiologic studies. While these measures are widely accepted as determinants of pulmonary function, abdominal adiposity may influence pulmonary function through a mechanism that is distinct from that of overall adiposity. Abdominal adiposity may restrict the descent of the diaphragm and limit lung expansion, compared to overall adiposity, which may compress the chest wall.[14] In most epidemiologic studies, waist circumference and/or waist/hip ratio represent abdominal adiposity. However, investigators proposed that abdominal height is a better indicator of visceral fat (the metabolically active fat depot) and, thus, is a better marker of abdominal adiposity.[15,16]

In this study, we investigated the association of total body adiposity and abdominal adiposity with FEV_1 and FVC in a random sample of the population in western New York state. We hypothesized that a specific effect of fat distribution on pulmonary function exists. In particular, we hypothesized that a greater accumulation of abdominal fat is associated with lower levels of FEV_1 and FVC, and that abdominal fatness is a better predictor of reduced pulmonary function than total body adiposity.

Materials and Methods

Study Subjects

We recruited participants from Erie and Niagara counties in western New York, as previously described.[17] In brief, we recruited a sample of the general population using lists supplied by the New York State Department of Motor Vehicles (respondents aged 35 to 65 years) and the Health Care Financing Administration (respondents aged $>$ 65 years). We used letters and telephone contact to recruit participants. All study protocols were approved by the University at Buffalo institutional review board. Approximately 59.4% of individuals who were contacted and were eligible for the study agreed to participate. Individuals with chronic lung disease, cancer, and prevalent cardiovascular disease (*eg*, prior myocardial infarction, coronary artery bypass graft surgery, angioplasty, or diagnosis of angina pectoris) were excluded from the study. We also excluded individuals with missing spirometry and anthropometry data, resulting in 2,153 individuals who were eligible for analysis.

Pulmonary Function Tests

Trained personnel performed spirometry between 6:30 and 9:30 AM according to American Thoracic Society recommendations.[18] We used two different pneumotachometers; one for the first 562 participants (Compact; Vitalograph Medical Instruments; Lexena, KS), and another for all other participants (model 2170 spirometer; Vitalograph Medical Instruments). We first performed two to three slow vital capacity practice maneuvers followed by at least three but no more than eight acceptable FVC maneuvers. We considered test results to be reproducible if the differences between the two best maneuvers were $\leq$ 200 mL.[18] We excluded 6.8% of participants due to pulmonary function test results that were not reproducible. All pulmonary function tests were performed while participants were in the sitting position.

We used linear regression to derive FEV_1 and FVC prediction equations for men and women separately using age, height, race, and gender in never-smokers free of respiratory disease in our sample (n = 981). We then calculated FEV_1 and FVC as the percentage of predicted values and the FEV_1/FVC ratio. When we compared the results obtained with our internal prediction equations to those obtained with external prediction equations from the National Health and Nutrition Examination Survey III, we found no important differences in the observed associations, and we reported only the results obtained using internal prediction equations.[19]

Interview

Trained interviewers collected demographic information, physical measurements, and detailed lifetime smoking histories during in-person interviews. We used two smoking variables for the analysis. The first one was smoking status (current smoker, former smoker, or never-smoker). Using a questionnaire, we classified individuals as current smokers if they were smoking at the time of the study, and as never-smokers if they had smoked $<$ 100 cigarettes in their lifetime. We classified all remaining individuals as former smokers. We also collected lifetime smoking histories by decade to compute the lifetime number of pack-years.

Physical Measurements

We instructed participants to wear light clothing for their study visit. The trained interviewers measured height using a wall-mounted stadiometer and weight using a balance beam scale. For waist and hip measurements, participants were instructed to stand erect with the abdomen relaxed, arms at their side, and feet together (without shoes). Interviewers used tapes to measure the waist at the narrowest circumference between the bottom of the ribcage and the top of the iliac crest following normal expiration. The interviewers measured hip circumference at the largest point between the iliac crest and the symphysis pubis. For abdominal height, interviewers used a Holtain-Kahn abdominal caliper.[20] Abdominal height was defined as the sagittal diameter of the abdomen measured by interviewers at the iliac crest while the participant was in the supine position. The measure of abdominal height is strongly correlated with visceral adipose tissue when compared to CT scans and MRIs as the "gold standard."[15,16,21] During standardization sessions for seven interviewers taking two observations on six subjects, the Pearson correlation coefficients were 0.97 for weight, 0.75 for the waist/hip ratio, and 0.81 for abdominal height. We refer to body weight and BMI as overall adiposity markers, and abdominal height, waist circumference, and waist/hip ratio as abdominal adiposity markers.

Analysis

We decided *a priori* to stratify analyses by gender. We computed the mean values including SDs for all relevant vari-

ables and the Pearson correlation coefficients to assess relation among physical measurements. For the multivariable analysis, we considered each of the following covariates because they were possibly associated with pulmonary function: smoking status; lifetime number of pack-years smoked; education; eosinophil count; and serum carotenoid level. Serum carotenoid measurements were available only for a subsample of subjects (n = 817).

In order to identify whether more obese individuals had difficulty performing the tests, we compared reproducibility across abdominal height categories. We compared differences between the best two FEV_1 and FVC measurements across abdominal height categories to investigate whether more obese subjects had difficulty with the test. There were no significant differences.

We analyzed trends in mean FEV_1 percent predicted and FVC percent predicted across quintiles of abdominal height using general linear models that were adjusted for covariates. To investigate the individual associations of each adiposity marker (*ie*, weight, BMI, waist circumference, waist/hip ratio, and abdominal height) with pulmonary function, we performed linear regression analysis. In addition to FEV_1 percent predicted and FVC percent predicted, we investigated the dependent variable FEV_1/FVC ratio. We entered each adiposity marker individually in multivariable models in order to analyze their contribution to the variation in FEV_1 percent predicted, FVC percent predicted, and FEV_1/FVC ratio, and to avoid multicollinearity. We defined a stronger association as one that yielded a lower p value based on the measurement properties (*ie*, less variability and/or higher coefficients) of the variables.

We investigated effect modification by BMI and smoking. We classified individuals into three strata according to the BMI categories < 25 kg/m^2; 25 to 30 kg/m^2; and > 30 kg/m^2, and three categories based on the mean number of pack-years of smoking. For all analyses, we used a statistical software package (SPSS, version 11.0; SPSS; Chicago, IL).[22]

Results

The mean age of participants in the sample was 56.8 years (SD, 11.3 years) for women and 58.5 years (SD, 12.5 years) for men. Approximately 6.5% of all participants were African-American. Raw FEV_1 and FVC values were higher for men, but once we removed the effects of age, height, and race, FEV_1 percent predicted and FVC percent predicted values were higher for women ($p < 0.001$). More women in our sample were current smokers, but men had a higher lifetime exposure to cigarettes ($p < 0.001$). The mean BMI values for women and men were 27.6 kg/m^2 (SD, 5.7 kg/m^2) and 28.3 kg/m^2 (SD, 4.4 kg/m^2), respectively.

Table 1 shows the characteristics of the study population as stratified by quartiles of abdominal height. Women in the highest quartile of abdominal height were more likely to be older, to be never-smokers or former smokers, to have lower pulmonary function, and to have higher weight, BMI, waist circumference, and waist/hip ratio. Men in the highest quartile of abdominal height were more likely to be former smokers, to have lower pulmonary function, and to have higher weight, BMI, waist circumference, and waist/hip ratio.

Table 2 summarizes the correlation coefficients for markers of overall and abdominal adiposity. Correlations were strong among adiposity markers, with the exception of waist/hip ratio, which showed a weaker correlation with the other markers. The correlations were similar for men and women.

Table 3 shows trends in pulmonary function by quartiles of adiposity markers in men and women. For women, all inverse trends were statistically significant at $p < 0.05$ except for the trend in weight, BMI, and waist-to-hip ratio for FEV_1 percent predicted. Similarly in men, all inverse trends were statistically significant. Individuals in the lowest quartile based on abdominal height had slightly better pulmonary function compared to individuals in the lowest quartiles of weight and BMI. We performed each analysis with log-transformed adiposity markers and obtained similar results; therefore, we present the nontransformed coefficients to ease interpretation.

Table 4 summarizes the regression coefficients for adiposity markers that were entered individually into FEV_1 percent predicted, FVC percent predicted, and FEV_1/FVC ratio linear regression models. Overall, there were negative associations of each adiposity marker with FEV_1 and FVC in men and women, but not all were statistically significant. In women, abdominal height ($p < 0.001$) and waist circumference ($p < 0.01$) were most strongly negatively associated with FEV_1; all five markers of adiposity were negatively associated with FVC (all $p < 0.05$). In women, models containing abdominal height explained the greatest variance in FEV_1 and FVC relative to other adiposity markers. In men, all markers were negatively and statistically significantly associated with FEV_1 percent predicted and FVC percent predicted ($p < 0.05$). Similarly in men, abdominal height and waist circumference explained the greatest proportion of variance in pulmonary function. All adiposity markers were positively and significantly associated with airway obstruction (*ie*, FEV_1/FVC ratio).

In linear regression models, we found decreases of 1.81% and 3.69%, respectively, in FEV_1 percent predicted per SD of abdominal height for women and men. For FVC percent predicted, the percentage decrease per SD was 2.96% for women and 5.25% for men. The decrease in FEV_1 percent predicted per SD of waist circumference for women and men was 1.17% and 2.80%, respectively, and the FVC decrease was 2.39% for women and 4.20% for men.

We found statistically significant interaction between abdominal height and BMI in men and women ($p < 0.10$) and, therefore, stratified the analysis by BMI. Table 5 shows the results of this analysis. In both men and women, abdominal height

Table 1—*Characteristics of Participants by Quartile of Abdominal Height

Variable	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Women (n = 1,168)				
Participants, No.	286	296	295	291
Age, yr	53.0 (11.0) [36.7–79.7]	58.5 (11.3) [37.1–79.8]	58.8 (11.0) [35.9–78.9]	58.8 (10.7) [37.0–79.0]
African American, %	1.4	5.1	7.8	9.6
Education, % high school or beyond	97.9	92.9	90.8	89.0
Smoking status, %				
Never-smoker	52.8	50.0	51.2	48.5
Former smoker	28.3	31.4	35.3	38.5
Current smoker	18.9	18.6	13.6	13.1
Lifetime smoking, pack-yr	8.4 (14.9)	9.5 (14.7)	8.3 (14.6)	10.8 (17.7)
FEV_1				
L	2.76 (0.64)	2.55 (0.51)	2.57 (0.55)	2.45 (0.55)
% predicted	99.50 (17.35)	98.92 (13.48)	99.31 (15.08)	94.82 (14.72)
FVC				
L	3.56 (0.70)	3.31 (0.62)	3.28 (0.68)	3.09 (0.67)
% predicted	102.33 (15.54)	101.21 (12.85)	100.03 (14.58)	94.46 (13.95)
FEV_1/FVC ratio, %	77.02 (8.52)	77.14 (6.23)	78.33 (6.67)	79.33 (7.31)
Difference between 2 best FEV_1 measurements, L	0.035 (0.039)	0.033 (0.031)	0.034 (0.033)	0.040 (0.039)
Difference between 2 best FVC measurements, L	0.054 (0.045)	0.052 (0.048)	0.059 (0.051)	0.054 (0.049)
Weight, kg	57.7 (6.1) [44.1–75.5]	65.4 (6.7) [49.8–91.4]	74.5 (8.7) [50.9–104.1]	90.8 (14.9) [52.7–155.7]
BMI, kg/m^2	22.0 (2.1) [16.2–28.6]	25.2 (2.3) [20.3–32.3]	28.4 (3.0) [19.2–36.3]	34.6 (5.2) [20.3–56.8]
Waist circumference, cm	71.9 (5.8) [56.0–94.0]	79.3 (6.3) [45.0–98.5]	88.1 (6.7) [69.0–107.5]	102.1 (11.2) [72.1–146.4]
Waist/hip ratio	0.79 (0.1) [0.6–1.0]	0.80 (0.1) [0.5–1.03]	0.83 (0.1) [0.7–1.1]	0.87 (0.1) [0.7–1.2]
Abdominal height, cm	16.2 (1.1) [13.1–17.8]	18.7 (0.6) [17.8–19.7]	21.0 (0.8) [19.7–22.4]	25.2 (2.4) [22.4–34.0]
Men (n = 985)				
Participants, No.	243	249	246	247
Age, yr	57.4 (13.2) [36.1–79.4]	58.6 (12.3) [36.7–79.4]	60.6 (11.2) [36.6–79.3]	59.6 (11.1) [36.5–78.7]
African American, %	6.2	7.2	7.3	8.1
Education, % high school or beyond	92.2	92.0	87.8	89.9
Smoking status, %				
Never-smoker	46.5	36.9	36.6	38.5
Former smoker	39.1	46.2	51.2	50.2
Current smoker	14.4	16.9	12.2	11.3
Lifetime smoking, pack-yr	10.9 (18.1)	16.4 (20.0)	16.8 (20.7)	16.9 (22.6)
FEV_1				
L	3.66 (0.78)	3.50 (0.85)	3.35 (0.81)	3.27 (0.79)
% predicted	101.55 (15.44)	96.50 (16.85)	94.81 (17.37)	90.62 (16.30)
FVC				
L	4.84 (0.90)	4.58 (0.94)	4.36 (0.95)	4.20 (0.91)
% predicted	105.77 (14.32)	99.13 (14.19)	96.23 (14.63)	91.01 (14.66)
FEV_1/FVC ratio, %	75.54 (7.68)	76.15 (8.64)	76.87 (8.12)	77.82 (7.69)
Difference between 2 best FEV_1 measurements, L	0.050 (0.042)	0.045 (0.039)	0.050 (0.044)	0.047 (0.041)
Difference between 2 best FVC measurements, L	0.067 (0.054)	0.067 (0.054)	0.066 (0.053)	0.066 (0.054)
Weight, kg	73.9 (7.8) [30.5–98.2]	82.1 (8.1) [60.9–103.6]	88.8 (9.0) [62.0–126.8]	104.5 (13.3) [74.3–159.1]
BMI, kg/m^2	24.3 (2.3) [12.4–30.0]	26.6 (2.2) [20.3–35.4]	28.9 (2.5) [21.8–43.9]	33.6 (3.9) [24.6–49.1]
Waist circumference, cm	86.3 (6.1) [58.0–106.4]	93.9 (5.8) [67.2–114.0]	100.4 (5.9) [70.0–118.0]	113.1 (9.4) [86.5–152.5]
Waist/hip ratio	0.92 (0.1) [0.8–1.1]	0.94 (0.1) [0.8–1.1]	0.96 (0.1) [0.7–1.1]	0.99 (0.1) [0.6–1.2]
Abdominal height, cm	18.5 (1.1) [13.9–19.9]	20.8 (0.6) [19.9–21.8]	22.7 (0.6) [21.8–24.0]	26.6 (2.3) [24.0–36.4]

*Values are given as the mean (SD) [range].

Table 2—*Partial Correlation Coefficients Adjusted for Age

Variables	Weight	BMI	Waist Circumference	Waist/ Hip Ratio
Women (n = 1,168)				
Weight				
BMI	0.93			
Waist circumference	0.88	0.88		
Waist/hip ratio	0.32	0.32	0.60	
Abdominal height	0.86	0.88	0.87	0.41
Men (n = 985)				
Weight				
BMI	0.89			
Waist circumference	0.87	0.87		
Waist/hip ratio	0.33	0.36	0.55	
Abdominal height	0.82	0.83	0.87	0.43

*All Pearson correlation coefficients were statistically significant at $p < 0.001$.

was negatively associated with FEV_1 percent predicted and FVC percent predicted in participants with a BMI ≥ 25 kg/m^2 ($p < 0.001$). In women with a BMI of < 25 kg/m^2, the association of FEV_1 percent predicted and abdominal height did not reach statistical significance ($p < 0.199$). In men, there was a statistically significant association of abdominal height and FVC percent predicted for a BMI of < 25 kg/m^2. In women, the association between abdominal height and airway obstruction was not significant for any BMI category. In men, abdominal height was positively associated with airway obstruction only for men with a BMI of 25 to 30 kg/m^2.

We found evidence for the statistical interaction of abdominal height and smoking, but only in women. When we stratified subjects based on the lifetime number of pack-years of smoking at the mean pack-years for women (*ie*, 0, < 9.24, and > 9.24 pack-years), we found that the inverse trends in abdominal height and pulmonary function were statistically significant only for never-smokers and women with < 9.24 pack-years of smoking.

Individuals with physician-diagnosed chronic airflow limitation had already been excluded from this analysis. However, we also investigated whether the inclusion of individuals with undiagnosed chronic airflow limitation would influence the results. We accomplished this by excluding those with an FEV_1 of $< 80\%$ predicted. Of 2,153 individuals included in

Table 3—*Trends in FEV_1 and FVC by Adiposity Markers

Variables	Quartile I (Lowest)	Quartile II	Quartile III	Quartile IV (Highest)	Difference Between Quartiles I and IV	p Value for Trend*
Women (n = 1,168)						
FEV_1 % predicted						
Weight (kg)	97.5 (95.8–99.2)	99.7 (98.0–101.4)	98.6 (96.9–100.3)	96.7 (95.0–98.4)	− 0.83	0.069
BMI, kg/m^2	97.6 (95.9–99.3)	99.8 (98.1–101.5)	98.3 (96.7–100.0)	96.9 (95.2–98.5)	− 0.70	0.090
Waist circumference, cm	98.1 (96.4–99.8)	100.3 (98.6–102.0)	98.4 (96.7–100.1)	95.8 (94.1–97.5)	− 2.33	0.003
Waist/hip ratio	97.7 (96.0–99.4)	99.2 (97.6–100.9)	98.2 (96.6–99.9)	97.3 (95.7–99.0)	− 0.39	0.433
Abdominal height, cm	99.0 (97.3–100.8)	99.0 (97.4–100.7)	99.2 (97.5–100.9)	95.3 (93.6–97.0)	− 3.75	0.002
FVC % predicted						
Weight, kg	100.7 (99.0–102.3)	101.3 (99.7–102.9)	99.5 (97.9–101.2)	96.5 (94.9–98.2)	− 4.13	0.001
BMI, kg/m^2	100.6 (98.9–102.2)	102.0 (100.4–103.6)	99.5 (97.9–101.2)	95.9 (94.3–97.6)	− 4.63	0.001
Waist circumference, cm	100.7 (99.1–102.4)	102.4 (100.8–104.1)	99.2 (97.5–100.8)	95.7 (94.1–97.3)	− 5.03	0.001
Waist/hip ratio	99.7 (98.0–101.3)	101.0 (99.4–102.7)	99.7 (98.0–101.3)	97.6 (96.0–99.3)	− 2.05	0.043
Abdominal height, cm	102.0 (100.3–103.6)	101.3 (99.7–102.9)	100.1 (98.4–101.7)	94.7 (93.1–96.4)	− 7.23	0.001
Men (n = 985)						
FEV_1 % predicted						
Weight, kg	96.9 (94.9–98.9)	96.0 (94.1–98.0)	97.2 (95.3–99.2)	93.1 (91.1–95.1)	− 3.79	0.018
BMI, kg/m^2	96.0 (94.0–98.0)	97.4 (95.4–99.3)	96.9 (94.9–98.8)	93.2 (91.2–95.2)	− 2.80	0.017
Waist circumference, cm	98.6 (96.6–100.6)	97.8 (95.8–99.7)	94.8 (92.9–96.8)	92.2 (90.3–94.2)	− 6.36	0.001
Waist/hip ratio	97.6 (95.6–99.6)	94.9 (92.9–96.9)	96.8 (94.8–98.8)	94.2 (92.2–96.1)	− 3.44	0.047
Abdominal height, cm	100.3 (98.3–102.3)	96.8 (94.9–98.7)	95.3 (93.3–97.2)	91.0 (89.1–93.0)	− 9.27	0.001
FVC % predicted						
Weight, kg	101.8 (99.9–103.7)	98.7 (96.9–100.5)	97.8 (95.9–99.6)	93.7 (91.9–95.6)	− 8.07	0.001
BMI, kg/m^2	100.6 (98.7–102.4)	99.8 (98.0–101.7)	98.2 (96.3–100.0)	93.5 (91.6–95.3)	− 7.05	0.001
Waist circumference, cm	103.0 (101.2–104.9)	100.4 (98.6–102.2)	96.2 (94.4–98.0)	92.4 (90.5–94.2)	− 10.65	0.001
Waist/hip ratio	101.9 (100.1–103.8)	97.7 (95.9–99.6)	97.7 (95.9–99.6)	94.7 (92.8–96.6)	− 7.24	0.001
Abdominal height, cm	105.3 (103.5–107.1)	99.3 (97.6–101.1)	96.4 (94.6–98.2)	91.1 (89.3–92.9)	− 14.15	0.001

*Values are given as the mean (95% confidence interval). Trends were adjusted for smoking status, pack-years of smoking, education, and eosinophils.

Table 4—*Regression Coefficients for Adiposity Markers Entered Into Separate Models Predicting FEV_1, FVC, and FEV_1/FVC

Variables	FEV_1 % Predicted		FVC % Predicted		FEV_1/FVC Ratio	
	β (SE)	R^2	β (SE)	R^2	β (SE)	R^2
Women (n = 1,168)						
Weight, kg	− 0.036 (0.03)	0.086	− 0.119 (0.03)†	0.045	0.083 (0.01)†	0.149
BMI, kg/m^2	− 0.130 (0.08)	0.087	− 0.383 (0.07)†	0.051	0.224 (0.04)†	0.150
Waist circumference, cm	− 0.086 (0.03)‡	0.090	− 0.176 (0.03)†	0.055	0.086 (0.02)†	0.145
Waist/hip ratio	− 5.200 (5.90)	0.085	− 14.539 (5.72)‡	0.035	8.150 (2.79)‡	0.127
Abdominal height, cm	− 0.503 (0.12)†	0.098	− 0.821 (0.12)†	0.068	0.297 (0.06)†	0.140
Men (n = 985)						
Weight, kg	− 0.102 (0.03)‡	0.140	− 0.208 (0.03)†	0.085	0.078 (0.02)†	0.179
BMI, kg/m^2	− 0.363 (0.11)†	0.142	− 0.666 (0.11)†	0.081	0.238 (0.05)†	0.179
Waist circumference, cm	− 0.233 (0.04)†	0.159	− 0.350 (0.04)†	0.117	0.089 (0.02)†	0.179
Waist/hip ratio	− 20.910 (8.40)‡	0.138	−41.410 (7.90)†	0.071	15.851 (3.92)†	0.135
Abdominal height, cm	− 1.152 (0.15)†	0.180	− 1.637 (0.14)†	0.162	0.373 (0.07)†	0.184

*Each model was adjusted for smoking status, lifetime number of pack-years smoked, education, and eosinophils; FEV_1/FVC ratio models were also adjusted for age, height, and race.
†$p \leq 0.001$.
‡$p < 0.05$.

the study, approximately 13.6% had an FEV_1 of < 80% predicted. We found clear differences in the association when we split the group using this criterion; namely, there was no inverse association of any adiposity markers with pulmonary function in the group with an FEV_1 of < 80% predicted (data not shown). When we considered serum carotenoids as covariates (which we previously reported to explain a proportion of variance in pulmonary function), we found no important differences in the reported associations of adiposity markers and pulmonary function (data not shown).

Discussion

We investigated the relation of a number of adiposity markers with pulmonary function in a population-based study. We found inverse associations of abdominal height and waist circumference with pulmonary function in men and women with BMI values of ≥ 25 kg/m^2. Abdominal height and waist circumference explained the greatest proportion of variance in FEV_1 and FVC relative to other markers of adiposity. Also, the inverse association of abdominal height and pulmonary function was evident only in women who had been classified as never-smokers or smokers in the lowest 50% of the sample in terms of lifetime pack-years of smoking.

Our results confirm our *a priori* hypothesis that abdominal adiposity is negatively associated with pulmonary function. The results of this study are particularly noteworthy in that abdominal height, which is a highly specific marker for visceral adiposity,[15,16] explained the greatest amount of variance in pulmonary function among all of the adiposity markers (*ie*, weight, BMI, waist/hip ratio, and waist circumference), according to R^2 values in the linear regression models. Visceral adipose tissue

Table 5—*Abdominal Height Regression Coefficients in Models Stratified by BMI

Variables	FEV_1 % Predicted		FVC % Predicted		FEV_1/FVC Ratio	
	β (SE)	p Value	β (SE)	p Value	β (SE)	p Value
Women						
BMI < 25 kg/m^2 (n = 445)	− 0.518 (0.40)	0.199	− 0.256 (0.50)	0.500	− 0.029 (0.20)	0.885
BMI 25–30 kg/m^2 (n = 378)	− 1.350 (0.42)	0.001	− 1.738 (0.42)	0.001	0.345 (0.19)	0.073
BMI > 30 kg/m^2 (n = 345)	− 1.193 (0.24)	0.001	− 1.238 (0.23)	0.001	0.056 (0.13)	0.658
Men						
BMI < 25 kg/m^2 (n = 224)	− 1.178 (0.64)	0.068	− 1.421 (0.59)	0.017	− 0.117 (0.32)	0.712
BMI 25–30 kg/m^2 (n = 466)	− 2.330 (0.36)	0.001	− 3.155 (0.33)	0.001	0.560 (0.19)	0.003
BMI > 30 kg/m^2 (n = 295)	− 1.808 (0.31)	0.001	− 1.889 (0.28)	0.001	0.073 (0.15)	0.629

*Each model was adjusted for smoking status, lifetime number of pack-years smoked, education, and eosinophil concentrations; FEV_1/FVC ratio models were also adjusted for age, height, and race.

influences circulating concentrations of interleukin-6, tumor necrosis factor-α, leptin, and adiponectin,[5–8] which are cytokines that may act via systemic inflammation to negatively affect pulmonary function. Therefore, abdominal height may negatively impact pulmonary function via the action of insulin resistance. Investigators reported an inverse association of serum leptin concentration with FEV_1 as well as higher levels of C-reactive protein, leukocytes, and fibrinogen, which are other markers of systemic inflammation.[23] Therefore, inflammation may be part of the link between impaired pulmonary function and mortality.[12,13,24,25] The concurrent measurement of inflammatory markers and insulin resistance markers may allow for the determination of whether the mechanism is inflammatory or mechanical in nature.

Another possible mechanism for the association of abdominal adiposity and pulmonary function is a mechanical limitation of chest expansion during the FVC maneuver. Increased abdominal mass may impede the descent of the diaphragm and increase thoracic pressure.[26] Abdominal adiposity is likely to reduce expiratory reserve volume via compressing the lungs and diaphragm.[27,28] This will result in lower FVC measurements, which we indeed observed via the strong inverse association of every adiposity marker with FVC in men and women. All spirometry maneuvers were performed with the subject in the sitting position. Therefore, we cannot rule out the influence of sitting during spirometry on reduced pulmonary function, as one study[29] reported small but statistically significant differences in FVC compared to standing spirometry in individuals with a BMI of > 30 kg/m^2. Also, there is evidence that FEV_1 values are larger if testing is performed with the subject in the standing position.[30] Current guidelines recommend either the standing or sitting position for spirometry.[18] The results obtained with these techniques may reveal interchangeable results.

Early investigations of pulmonary function and weight showed a positive association between these variables. In our study, weight was inversely associated with pulmonary function in men and women. Our findings support the hypothesis that the relationship of pulmonary function and overall weight is now a more complex issue. The inverse association may be partially explained by changes in the prevalence of adiposity in more recent decades,[31] as a large proportion of individuals are classified into higher BMI categories.

It is difficult to tease apart the effects of BMI and abdominal adiposity due to their high correlation. Linear regression models became unstable when we included correlated predictors in models simultaneously. Therefore, we presented the association of relative and abdominal adiposity markers and pulmonary function separately, as well as the association of abdominal adiposity and pulmonary function stratified by BMI category. These results suggest that both overall and abdominal adiposity are negatively associated with FEV_1 and FVC, and support the hypothesis that abdominal adiposity markers (*ie*, abdominal height and waist circumference) have better explanatory power than total body adiposity measured as BMI or weight. Abdominal height and waist circumference are highly correlated; however, we recognize that abdominal height, although probably a better marker for visceral adipose tissue compared to waist circumference, presents a more challenging measurement to obtain.[32]

The finding of slightly higher pulmonary function in the lowest abdominal height quartile compared to weight and BMI quartiles supports the notion that having a lower abdominal height may be a better indicator of overall health compared to having a low BMI or weight, since individuals with a low BMI may have varying levels of abdominal adiposity, depending on gender. However, this finding may also be due to chance.

When we examined airway obstruction in relation to abdominal adiposity in our study, we found statistically significant inverse associations of abdominal height and airway obstruction when BMI is < 25 kg/m^2, and positive associations when BMI is > 25 kg/m^2. This positive association of airway obstruction with increasing relative and abdominal adiposity may suggest that the association is due to the strong association of FVC and abdominal adiposity.

We found the highest prevalence of obstruction (*ie*, FEV_1/FVC ratio, $< 80\%$) in the lowest quartiles of BMI and abdominal height. These results support previous findings by Sin et al[33] of no significant increased risk of obstruction (*ie*, FEV_1/FVC ratio, $< 80\%$) in obese individuals (highest BMI quintile compared to other quintiles) in the National Health and Nutrition Examination Survey III sample. These results suggest that obesity is not associated with airway obstruction based on spirometry, but rather may be more associated with symptoms of asthma and obstruction.[33,34]

The inverse association of abdominal height and FEV_1 in women and men was limited to those with BMI values of ≥ 25 kg/m^2. The association of abdominal height and FVC in women was statistically significant in those with BMI values of ≥ 25 kg/m^2. In men, however, there was an inverse association of abdominal height and FVC in every BMI category. These results suggest that abdominal adiposity can

negatively influence pulmonary function even when individuals are classified as being overweight using standard measures of obesity (*ie*, BMI, ≥ 25 kg/m^2).

When we stratified by smoking status, we found the strongest associations of abdominal height and pulmonary function in women who were never-smokers as well as in women who were in the lowest 50% of the sample in terms of lifetime number of pack-years of smoking. Therefore, the null associations in women who have smoked > 9 pack-years in their lifetime and in individuals with an FEV_1 of $< 80\%$ predicted may cause a nonlinear relationship of abdominal height and pulmonary function.

Other investigators explored the association of obesity with pulmonary function. Canoy et al[35] analyzed the association of waist/hip ratio and pulmonary function in the European Prospective Investigation Into Cancer and Nutrition study, and reported an inverse association that remained significant after adjustment for BMI. Our results are similar in that the association remained significant in never-smokers. Chen et al[36] analyzed waist circumference and pulmonary function in a sample of men and women in the United Kingdom. These authors found inverse associations of waist circumference and pulmonary function. Harik-Khan et al[37] investigated the association of fat distribution and pulmonary function using waist/hip ratio. They reported an inverse association of FEV_1 and waist/hip ratio in men only, which was similar to our findings. Our results also supported an inverse association between FVC and waist/hip ratio. Lazarus et al[38] found no inverse associations of waist circumference or waist/hip ratio with FVC in women. These authors also reported an inverse association of abdominal girth/hip breadth ratio with pulmonary function after adjustment for BMI in men over a narrow age range in the Normative Aging Study.[39] We found no evidence for effect modification by age in our study. Collins et al[40] examined 42 normal to mildly obese firefighters and found decreased pulmonary function in men with a waist/hip ratio of > 0.95.

Longitudinal studies of pulmonary function decline allow for the determination of the effect of changes in body composition on pulmonary function. These studies[41–44] have implicated weight gain as an important predictor of pulmonary function decline, an association that appears to be stronger in men. In one study[45] of obese women (BMI, > 30 kg/m^2), weight loss during a 6-month period improved FVC and FEV_1; however, it did not change the FEV_1/FVC ratio. A dietary intervention of weight loss in obese men showed improved FEV_1 and FVC with the loss of abdominal fat after 3 months on a hypocaloric Mediterranean diet.[46] The results of these studies combined suggest that weight gain is associated with pulmonary function decline; however, these negative effects on pulmonary function may be potentially reversible with weight loss.

The finding of an inverse association of abdominal height and waist circumference and the stronger association of abdominal adiposity and pulmonary function in men points to the importance of what has been called "apple vs pear-shaped" body types. As with other chronic conditions, increased abdominal adiposity or having an "apple-shape" may be an important indicator of lung health. Further research should be focused on characterizing the mechanism for the association of abdominal adiposity and reduced pulmonary function.

The major strength of our study lies in the availability of multiple standardized anthropometric measurements, spirometry, and detailed lifetime smoking histories. We were able to analyze the contribution of overall and abdominal adiposity markers to variation in pulmonary function, including abdominal height. Our study is a random sample of individuals from the general population, so we were able to investigate this association in nonobese individuals. In addition, the results were similar when we modeled raw FEV_1 and FVC instead of using the percent predicted form.

The cross-sectional nature of this study is a limitation, as it does not provide information about a temporal sequence. Longitudinal studies are needed to further investigate how abdominal adiposity and changes in abdominal adiposity influence pulmonary function. The findings should be interpreted with caution due the moderate participation rate. In addition, we cannot generalize these findings to children or young adults. A study of abdominal adiposity and pulmonary function in subjects in these age groups would be of interest because these individuals may not have yet attained maximal pulmonary function, which may influence pulmonary function decline and mortality risk.

Conclusion

We found negative associations of abdominal adiposity and pulmonary function in men and women from the general population that are not limited to severely obese persons. Abdominal adiposity is an important determinant of impaired pulmonary function, and it is of greater importance than overall adiposity markers such as weight and BMI. We suggest that investigators consider the inclusion of

markers of abdominal adiposity as a potential confounding factor when investigating the determinants of pulmonary function.

ACKNOWLEDGMENT: We thank Richard W. Browne in the Department of Clinical Laboratory Science at the University at Buffalo for laboratory measurements. We would also like to thank the personnel at the Center for Preventive Medicine, University at Buffalo, for their contribution to the study.

References

1 Sowers JR. Obesity as a cardiovascular risk factor. Am J Med 2003; 115(suppl):37S–41S
2 Reaven GM. Banting lecture 1988: role of insulin resistance in human disease. Diabetes 1988; 37:1595–1607
3 Dandona P, Aljada A, Bandyopadhyay A. Inflammation: the link between insulin resistance, obesity and diabetes. Trends Immunol 2004; 25:4–7
4 Garg R, Tripathy D, Dandona P. Insulin resistance as a proinflammatory state: mechanisms, mediators, and therapeutic interventions. Curr Drug Targets 2003; 4:487–492
5 Kern PA, Ranganathan S, Li C, et al. Adipose tissue tumor necrosis factor and interleukin-6 expression in human obesity and insulin resistance. Am J Physiol Endocrinol Metab 2001; 280:E745–E751
6 Staiger H, Tschritter O, Machann J, et al. Relationship of serum adiponectin and leptin concentrations with body fat distribution in humans. Obes Res 2003; 11:368–372
7 Armellini F, Zamboni M, Bosello O. Hormones and body composition in humans: clinical studies. Int J Obes Relat Metab Disord 2000; 24(suppl):S18–S21
8 Gasteyger C, Tremblay A. Metabolic impact of body fat distribution. J Endocrinol Invest 2002; 25:876–883
9 Kern P, DiGregorio G, Lu T, et al. Adiponectin expression from human adipose tissue: relation to obesity, insulin resistance, and tumor necrosis factor-α expression. Diabetes 2003; 52:1779–1785
10 Sin DD, Man P. Why are patients with chronic obstructive pulmonary disease at increased risk of cardiovascular diseases? The potential role of systemic inflammation in chronic obstructive pulmonary disease. Circulation 2003; 107:1514–1519
11 Gan W, Man S, Senthilselvan A, et al. Association between chronic obstructive pulmonary disease and systemic inflammation: a systematic review and meta-analysis. Thorax 2004; 59:574–580
12 Schunemann HJ, Dorn J, Grant BJ, et al. Pulmonary function is a long-term predictor of mortality in the general population: 29-year follow-up of the Buffalo Health Study. Chest 2000; 118:656–664
13 Ryan G, Knuiman MW, Divitini ML, et al. Decline in lung function and mortality: the Busselton Health Study. J Epidemiol Community Health 1999; 53:230–234
14 Biring MS, Lewis MI, Liu JT, et al. Pulmonary physiologic changes of morbid obesity. Am J Med Sci 1999; 318:293–297
15 Pouliot MC, Despres JP, Lemieux S, et al. Waist circumference and abdominal sagittal diameter: best simple anthropometric indexes of abdominal visceral adipose tissue accumulation and related cardiovascular risk in men and women. Am J Cardiol 1994; 73:460–468
16 van der Kooy K, Leenen R, Seidell JC, et al. Abdominal diameters as indicators of visceral fat: comparison between magnetic resonance imaging and anthropometry. Br J Nutr 1993; 70:47–58
17 Schunemann HJ, Freudenheim JL, Grant BJ. Epidemiologic evidence linking antioxidant vitamins to pulmonary function and airway obstruction. Epidemiol Rev 2001; 23:248–267
18 American Thoracic Society. Standardization of spirometry, 1994 update. Am J Respir Crit Care Med 1995; 152:1107–1136
19 Hankinson J, Odencrantz J, Fedan K. Spirometric reference values from a sample of the general US population. Am J Respir Crit Care Med 1999; 159:179–187
20 Kahn HS. Choosing an index for abdominal obesity: an opportunity for epidemiologic clarification. J Clin Epidemiol 1993; 46:491–494
21 Kvist H, Chowdhury B, Grangard U, et al. Total and visceral adipose-tissue volumes derived from measurements with computed tomography in adult men and women: predictive equations. Am J Clin Nutr 1988; 48:1351–1361
22 Statistical Package for Social Sciences. SPSS for Windows, version 11.0. Chicago, IL: SPSS, 2005
23 Sin DD, Man SF. Impaired lung function and serum leptin in men and women with normal body weight: a population based study. Thorax 2003; 58:695–698
24 Mannino DM, Buist AS, Petty TL, et al. Lung function and mortality in the United States: data from the First National Health and Nutrition Examination Survey follow up study. Thorax 2003; 58:388–393
25 Pelkonen M, Notkola IL, Tukiainen H, et al. Smoking cessation, decline in pulmonary function and total mortality: a 30 year follow up study among the Finnish cohorts of the Seven Countries Study. Thorax 2001; 56:703–707
26 Sugerman H, Windsor A, Bessos M, et al. Intra-abdominal pressure, sagittal abdominal diameter and obesity comorbidity. J Intern Med 1997; 241:71–79
27 Koenig SM. Pulmonary complications of obesity. Am J Med Sci 2001; 321:249–279
28 Ray CS, Sue DY, Bray G, et al. Effects of obesity on respiratory function. Am Rev Respir Dis 1983; 128:501–506
29 Gudmundsson G, Cerveny M, Shasby DM. Spirometric values in obese individuals: effects of body position. Am J Respir Crit Care Med 1997; 156:998–999
30 Townsend MC. Spirometric forced expiratory volumes measured in the standing versus the sitting posture. Am Rev Respir Dis 1984; 130:123–124
31 Hedley AA, Ogden CL, Johnson CL, et al. Prevalence of overweight and obesity among US children, adolescents, and adults, 1999–2002. JAMA 2004; 291:2847–2850
32 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; 241:11–18
33 Sin DD, Jones RL, Man SFP. Obesity is a risk factor for dyspnea but not for airflow obstruction. Arch Intern Med 2002; 162:1477–1481
34 Chinn S, Jarvis D, Burney P. Relation of bronchial responsiveness to body mass index in the ECRHS. Thorax 2002; 57:1028–1033
35 Canoy D, Luben R, Welch A, et al. Abdominal obesity and respiratory function in men and women in the EPIC-Norfolk Study, United Kingdom. Am J Epidemiol 2004; 159:1140–1149
36 Chen R, Tunstall-Pedoe H, Bolton-Smith C, et al. Association of dietary antioxidants and waist circumference with pulmonary function and airway obstruction. Am J Epidemiol 2001; 153:157–163
37 Harik-Khan RI, Wise RA, Fleg JL. The effect of gender on the relationship between body fat distribution and lung function. J Clin Epidemiol 2001; 54:399–406
38 Lazarus R, Gore CJ, Booth M, et al. Effects of body

composition and fat distribution on ventilatory function in adults. Am J Clin Nutr 1998; 68:35–41
39 Lazarus R, Sparrow D, Weiss ST. Effects of obesity and fat distribution on ventilatory function: the normative aging study. Chest 1997; 111:891–898
40 Collins LC, Hoberty PD, Walker JF, et al. The effect of body fat distribution on pulmonary function tests. Chest 1995; 107:1298–1302
41 Bottai M, Pistelli F, Di Pede F, et al. Longitudinal changes of body mass index, spirometry and diffusion in a general population. Eur Respir J 2002; 20:665–673
42 Chen Y, Horne SL, Dosman JA. Body weight and weight gain related to pulmonary function decline in adults: a six year follow up study. Thorax 1993; 48:375–380
43 Carey IM, Cook DG, Strachan DP. The effects of adiposity and weight change on forced expiratory volume decline in a longitudinal study of adults. Int J Obes Relat Metab Disord 1999; 23:979–985
44 Wise RA, Enright PL, Connett JE, et al. Effect of weight gain on pulmonary function after smoking cessation in the Lung Health Study. Am J Respir Crit Care Med 1998; 157:866–872
45 Aaron SD, Fergusson D, Dent R, et al. Effect of weight reduction on respiratory function and airway reactivity in obese women. Chest 2004; 125:2046–2052
46 De Lorenzo A. Body composition analysis and changes in airways function in obese adults after hypocaloric diet. Chest 2001; 119:1409–1415