Body fat distribution, body composition, and respiratory function in elderly men

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ABSTRACT

Background: Most population studies have reported weak or non-significant associations between body mass index (BMI; in kg/m²) and lung function.

Objective: This study focused on the distinct effects of fat distribution and body composition on lung function and examined these relations in elderly men.

Design: The study was a cross-sectional evaluation of 2744 men aged 60–79 y who were free of cardiovascular disease and cancer and were drawn from general practices in 24 British towns. Anthropometric and body-composition [including fat mass (FM), fat-free mass (FFM), and percentage body fat (%BF) evaluated with bioelectric impedance] measurements were made, and lung function was examined by using spirometry.

Results: Height-standardized forced expiratory volume in 1 s (FEV₁) was diminished only in lean (BMI < 22.5) and obese (BMI ≥ 30) men, but forced vital capacity (FVC) tended to decrease with increasing BMI (P < 0.01). All other measures of adiposity [ie, waist circumference (WC), waist-to-hip ratio (WHR), FM, and %BF] were significantly and inversely related to FEV₁ and FVC after adjustment for confounders, including age and cigarette smoking (all: P < 0.05). This was seen both in nonobese (BMI < 30) and obese men. FFM was positively associated with FEV₁ (P = 0.03) and to a lesser extent with FVC. Higher BMI and FFM were both associated with reduced odds of a low FEV₁/FVC ratio (ie, <70%).

Conclusion: Total body fat and central adiposity are inversely associated with lung function, but increased FFM reflecting increases in muscle mass is associated with increased lung function and lower odds of low FEV₁/FVC in the elderly. Am J Clin Nutr 2005;82:996–1003.

KEY WORDS Lung function, body mass index, BMI, fat distribution, body composition, fat-free mass

INTRODUCTION

Impaired lung function—in particular, low forced expiratory volume in 1 s (FEV₁)—is associated with increased morbidity and mortality (1, 2), and it is well recognized that severe clinical obesity is associated with impairment of lung function (3, 4). Most population studies that examined the relation between obesity and lung function used body mass index (BMI) as a measure of overall adiposity, and nonsignificant or weak associations have been reported, with diminished lung function at both extremes of the BMI distribution (ie, thin or obese) (5, 6). However, BMI does not take into account the pattern of fat distribution or body composition and cannot adequately distinguish between fat mass (FM) and fat-free (ie, lean) mass (FFM). In the past few years, it was suggested that these factors may have distinct effects on pulmonary function (5–10). Several studies reported inverse associations between lung function and measures of central adiposity such as the waist circumference (WC) and the waist-to-hip ratio (WHR) (6, 7, 10–16). In the few reports that investigated the association between the individual components of body composition (ie, FM and FFM) and lung function, FFM was shown to be inversely related to lung function but positively related to FFM (6–10). It is well established that, with advancing age, lung function declines (17), and there is a tendency for visceral fat to increase and muscle mass to decline (18). However, only a few studies have considered the associations between body-fat distribution, body composition, and lung function in the elderly (7, 8). The aim of the current study was to examine the relation between BMI, central fat distribution (ie, WC and WHR), and body composition [ie, percentage body fat (%BF), FM, and FFM] and the lung function in a large population study of elderly men who were free of cardiovascular disease (CVD), diabetes, and cancer.

SUBJECTS AND METHODS

Subjects

The British Regional Heart Study is a prospective study of CVD in 7735 men aged 40–59 y who were selected from the age-sex registers of one general practice in each of 24 British towns and who were screened between 1978 and 1980 (19). In 1998–2000, all surviving men, now aged 60–79 y, were invited for a 20-y follow-up examination.

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All men completed a questionnaire that included questions on their medical history and lifestyle behavior. The men were asked to fast for ≥6 h, during which time they were instructed to drink only water; then they were to appear for measurement at a specified time between 0800 and 1800. All men were asked to provide a blood sample, which was collected with the use of the Sarstedt Monovette system (Sarstedt, Numbrecht, Germany). Seventy-seven percent of survivors (n = 4252 men) attended for examination. Because adiposity is strongly related to type 2 diabetes and because diabetics have been shown to have poor lung function (20, 21), men with a physician’s diagnosis of diabetes and those with a fasting glucose concentration of ≥7 mmol/L [by World Health Organization (WHO) criteria; 22] were considered to have prevalent diabetes and were excluded (n = 497). We also excluded men who reported a previous diagnosis of coronary heart disease, angina, or stroke (n = 831) because many of these men are likely to have impaired lung function and because a diagnosis of CVD may lead to weight reduction (23). An additional 160 men with a diagnosis of cancer were excluded. Respiratory function tests were not available in 20 men, so that data on 2744 men were available for analysis.

All men provided informed written consent, and the investigation was carried out in accordance with the Declaration of Helsinki. Ethical approval was provided by all relevant local research ethics committees.

Anthropometric measurements

The anthropometric measurements at the 20-y reexamination included height, weight, waist and hip circumference, %BF, and percentage FM. Subjects were measured in light clothing without shoes. Height and weight were both measured standing. Height was measured with a Harpenden stadiometer (Critikon Service Center, Reading, United Kingdom) to the last complete 0.1 cm and weight with a Soehnle digital electronic scale to the last complete 0.1 kg. BMI (in kg/m²) was calculated for each man. BMI was not available in 2 men. Waist and hip circumferences were measured in duplicate with an insertion tape (CMS Ltd., London, United Kingdom); hip circumference was measured at the point of maximum circumference over the buttocks. The waist measurement was taken from the midpoint between the iliac crest and the lower ribs measured at the sides. The WHR was calculated as WC divided by hip circumference (both: in cm). Waist circumference (WC) was not available in 8 men, and WHR was missing in 9 men. Within-subject variation for WC, BMI, and WHR was examined in a small repeatability study of 110 subjects measured by the same team of observers on both occasions. The correlations between measurements taken 1 wk apart were 0.995 for BMI, 0.992 for WC, and 0.928 for WHR. The within-subject correlations for WC were very similar in non-obese and obese men (r = 0.988 and 0.968, respectively). FM and %BF were estimated by using bioelectric impedance method using the Bodystat 500 apparatus (Bodystat Ltd, Douglas, United Kingdom) and applying the equation of Deurenberg et al (24), which has been validated in an elderly population. FFM was calculated as 67.10 × height (in m²)/resistance (in Ω) + 7. FM was calculated as body weight – FFM. The %BF was calculated as (body weight – FFM)/body weight. Data on %BF were not available in 84 men. The correlations between measurements taken 1 wk apart were 0.67 for FFM and 0.75 for FM. WHR and WC were used as measures of abdominal (central) adiposity, and BMI, FM, and %BF were used as measures of general adiposity.

Lung function

After instruction and a practice attempt, each subject performed a minimum of 3 forced expiratory maneuvers to provide estimates of forced vital capacity (FVC) and FEV₁. FVC is the maximum volume of air expired during forced expiration and is primarily an indicator of lung volume (25). FEV₁ is the volume of air expired in the first second of forced expiration and is influenced by lung volume and airflow obstruction. Tests were carried out standing and without nose clips. A Vitalograph Compact II instrument (Vitalograph Ltd, Buckingham, United Kingdom) was used, which was calibrated at least twice a day by using a precision syringe. FEV₁ and FVC were recorded for the best test, which was defined in accordance with American Thoracic Society recommendations (26). Cole (27) showed that dividing by the height squared is the most appropriate way of standardizing lung function by stature. FEV₁ and FVC were height standardized to the average height (ie, 1.73 m) of the subjects in the study. Thus, height-standardized FEV₁ (or FVC) = FEV₁ (or FVC) × (1.73/height²). We defined a ratio of FEV₁ to FVC (an indicator of airflow obstruction) of <70% as low. Possible chronic obstructive pulmonary disease (COPD) was defined on the basis of an FEV₁/FVC of <70% (28). The men were asked about regular treatment and were required to bring their medication to the examination session. The medication was coded according to the British National Formulary (BNF) codes (29). Respiratory medication included BNF codes 3.1–3.10 (medication for the respiratory system). The category “men with respiratory problems” included men on respiratory medication.

Cardiovascular disease risk factors

Details of measurement and the methods of classifying by smoking status, physical activity, BMI, and social class in this cohort were described previously (19, 29). From the combined information at initial screening (1978–1980) and follow-up questionnaires in 1996 and at 20-y rescreening, the men were classified into 5 smoking groups: those who had never smoked, those who had stopped smoking before screening, smokers at initial screening who stopped smoking between screening and the 1996 follow-up, smokers at screening and in 1996 who stopped smoking after 1996, and current smokers at the 20-y rescreening. The longest-held occupation of each man was recorded at initial screening and coded in accordance with the Registrar General’s occupational classification into 6 socioeconomic groups, which were named I, II, and III nonmanual (nonmanual groups) and IV, V, and V manual (manual groups). Those whose longest occupation was in military service formed a 7th socioeconomic group. On the basis of the frequency and type of activity, a physical activity score was derived for each man, and the men were grouped into 6 broad categories: inactive, occasional, light, moderate, moderately vigorous, and vigorous. These categories were strongly related to both pulse rate and FEV₁ (30). The men were also asked to report the number of alcoholic drinks consumed per week, and they were classified into 5 groups: none, <1 drink/d, 1–2 drinks/d, 3–4 drinks/d, and ≥5 drinks/d (1 drink = 10 g alcohol).

Statistical analysis

Statistical analyses were performed with SAS software (version 8.2; SAS Institute Inc, Cary NC). Overweight (BMI 25–29.9) and obesity (BMI ≥ 30) were defined on the basis of
TABLE 1
Baseline characteristics of study participants

<table>
<thead>
<tr>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Age (y)</td>
</tr>
<tr>
<td>FEV₁ (L)</td>
</tr>
<tr>
<td>FVC (L)</td>
</tr>
<tr>
<td>FEV₁:FVC ratio (%)</td>
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<tr>
<td>FEV₁:FVC &lt; 70 (%)</td>
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<tr>
<td>FEV₁:FVC 61–69 (%)</td>
</tr>
<tr>
<td>FEV₁:FVC ≥ 60 (%)</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
</tr>
<tr>
<td>Waist-to-hip ratio (cm)</td>
</tr>
<tr>
<td>Percentage body fat (%)</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
</tr>
<tr>
<td>Fat-free mass (kg)</td>
</tr>
<tr>
<td>Current smokers (%)</td>
</tr>
<tr>
<td>Physically active (%)</td>
</tr>
<tr>
<td>Heavy drinkers (%)</td>
</tr>
<tr>
<td>Manual socioeconomic group (%)</td>
</tr>
</tbody>
</table>

TABLE 2
Correlations between the anthropometric measures and age in men 60–79 y old

<table>
<thead>
<tr>
<th>Age</th>
<th>Height</th>
<th>BMI</th>
<th>Waist circumference</th>
<th>WHR</th>
<th>Percentage body fat</th>
<th>Fat mass</th>
<th>Fat-free mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>-0.18</td>
<td>-0.09</td>
<td>-0.04²</td>
<td>0.01²</td>
<td>-0.08</td>
<td>-0.13</td>
<td>-0.08</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>1.00</td>
<td>0.01²</td>
<td>0.21</td>
<td>-0.007</td>
<td>0.04</td>
<td>0.25</td>
<td>0.43</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>1.00</td>
<td>0.87</td>
<td>0.53</td>
<td>0.52</td>
<td>0.76</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>1.00</td>
<td>0.74</td>
<td>0.54</td>
<td>0.76</td>
<td>0.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHR (cm)</td>
<td>1.00</td>
<td>0.38</td>
<td>0.46</td>
<td>0.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage body fat (%)</td>
<td>1.00</td>
<td>0.90</td>
<td>-0.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>1.00</td>
<td>0.03²</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat-free mass (kg)</td>
<td>1.00</td>
<td></td>
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</table>

1 WHR, waist-to-hip ratio. All correlations are significant (P < 0.001) unless indicated otherwise.
2 Not significant.

RESULTS
The characteristics of the study sample are given in Table 1. Approximately 14% of the men were current cigarette smokers. Their BMIs ranged from 14.46 to 47.56 (x: 26.63). An FEV₁:FVC of 70% was found in 23.8% of the men, and 13.8% had an even lower ratio of 61–69%. Mean FEV₁, FVC, and FEV₁:FVC declined significantly with increasing age (P < 0.0001). The correlation between age and FEV₁, FVC, and FEV₁:FVC was r = -0.32, -0.33, and -0.10, respectively (all: P < 0.0001). The correlation between the anthropometric measures and their correlation with age are shown in Table 2. BMI and WC were highly correlated (r = 0.87). BMI also showed strong correlations with FM and to a lesser degree with %BF and WHR, and it was positively associated with FFM. Although mean BMI, %BF, FM, and FFM declined with increasing age, no significant association was seen between age and WC or WHR.

The age-adjusted correlations between the adiposity measures and height-standardized lung function (i.e., FEV₁ and FVC) and FEV₁:FVC are shown in Table 3. FEV₁ and FVC are highly correlated (r = 0.79). BMI showed no significant correlation with FEV₁ but was inversely correlated with FVC. However, all other measures of adiposity (i.e., WC, WHR, FM, and %BF) were inversely correlated with FVC and FEV₁. FFM was positively correlated with FEV₁, and to a lesser extent with FVC. BMI and FFM were both positively correlated with FEV₁:FVC, but WHR was inversely correlated with FEV₁:FVC. No association was seen between the other adiposity measures and FEV₁:FVC.
The mean FEV₁ according to the adiposity measures adjusted for age, socioeconomic status, alcohol intake, smoking, and physical activity are shown in Figure 1. Mean FEV₁ was lowest in the leanest group and in the obese (P < 0.0001, F test on 4 df for overall differences between the groups); thus, a test for linear trend with increasing BMI was not significant. Mean FEV₁ tended to decrease with increasing WC, WHR, and %BF. FEV₁ was lower only in those in the highest category of FM. FFM showed weak inverse associations with lung function in overweight and obese men but not in lean men (FEV₁: P = 0.02; FVC: P = 0.14). Exclusion attenuated the reduced mean FEV₁ in men with low BMI and strengthened the inverse associations seen between the adiposity measures and FEV₁. The inverse associations seen with FVC remained significant after exclusion. The positive linear trend seen between FFM and FEV₁ was attenuated (P for linear trend = 0.14), but there were overall significant differences between the groups (P = 0.01, F test for 4 df), and mean FEV₁ was significantly lower only in those in the lowest FFM group; there was little difference between the other groups. Mean (±SE) FEV₁ was 2.71 ± 0.03, 2.80 ± 0.02, 2.85 ± 0.02, 2.82 ± 0.02, and 2.80 ± 0.03 L for the 5 FFM groups, respectively (P = 0.0006 for the lowest group compared with the rest). Mean FVC remained significantly lower in those with low FFM than in the rest (3.31 ± 0.46 L, respectively; P = 0.0009). The exclusion of men who reported weight loss in the previous 3 y (n = 271) tended to strengthen the observed inverse associations, further reduced the lower FEV₁ in men with low FFM, and further attenuated the reduced FEV₁ in men with low BMI. The trend (inverse) for BMI and FEV₁ was now of marginal significance (P = 0.06; adjusted FEV₁ for the 5 groups: 2.78 ± 0.04, 2.82 ± 0.02, 2.86 ± 0.02, 2.78 ± 0.03, and 2.71 ± 0.03 L, respectively).

We repeated the analyses by excluding the men with possible COPD (FEV₁/FVC < 0.70) (n = 547). Exclusion attenuated the reduced mean FEV₁ in men with low BMI and strengthened the inverse associations seen between the adiposity measures and FEV₁. The inverse associations seen with FVC remained significant after exclusion. The positive linear trend seen between FFM and FEV₁ was attenuated (P for linear trend = 0.14), but there were overall significant differences between the groups (P = 0.01, F test for 4 df), and mean FEV₁ was significantly lower only in those in the lowest FFM group; there was little difference between the other groups. Mean (±SE) FEV₁ was 2.71 ± 0.03, 2.80 ± 0.02, 2.85 ± 0.02, 2.82 ± 0.02, and 2.80 ± 0.03 L for the 5 FFM groups, respectively (P = 0.0006 for the lowest group compared with the rest). Mean FVC remained significantly lower in those with low FFM than in the rest (3.31 ± 0.46 L, respectively; P = 0.0009). The exclusion of men who reported weight loss in the previous 3 y (n = 271) tended to strengthen the observed inverse associations, further reduced the lower FEV₁ in men with low FFM, and further attenuated the reduced FEV₁ in men with low BMI. The trend (inverse) for BMI and FEV₁ was now of marginal significance (P = 0.06; adjusted FEV₁ for the 5 groups: 2.78 ± 0.04, 2.82 ± 0.02, 2.86 ± 0.02, 2.78 ± 0.03, and 2.71 ± 0.03 L, respectively).

TABLE 1. Mean forced expiratory volume in 1 s (FEV₁) by adiposity measures after adjustment for age, socioeconomic group, alcohol intake, smoking status, and physical activity. P value for linear trend is indicated for each measure. n = 267, 618, 859, 608, and 390 for BMI (in kg/m²) categories of <22.5, 22.5–24.9, 25–27.4, 27.5–29.9, and >30, respectively; n = 266, 612, 865, 613, and 380 for waist circumference categories of <84, 84–92, 92.1–99.3, 99.4–106.3, and >106.4 cm, respectively; n = 271, 625, 841, 608, and 390 for waist-to-hip ratio categories of <0.86, 0.86–0.91, 0.92–0.96, 0.97–1.0, and >1.01, respectively; n = 263, 595, 826, 597, and 379 for percentage body fat categories of <16.8%, 16.8–23.8%, 23.9–30.2%, 30.3–37.4%, and >37.5%, respectively; n = 261, 603, 830, 593, and 373 for fat mass categories of <24.5, 24.5–31.9, 32–37.7, 37.8–42.4, and >42.5 kg, respectively; n = 352, 583, 818, 611, and 333 for fat-free mass categories of <43.3, 43.3–48.0, 48.1–53.1, 53.2–59.0, and >59.1 kg, respectively.

The mean FEV₁ according to the adiposity measures adjusted for age, socioeconomic status, alcohol intake, smoking, and physical activity are shown in Figure 1. Mean FEV₁ was lowest in the leanest group and in the obese (P < 0.0001, F test on 4 df for overall differences between the groups); thus, a test for linear trend with increasing BMI was not significant. Mean FEV₁ tended to decrease with increasing WC, WHR, and %BF. FEV₁ was lower only in those in the highest category of FM. FFM showed a significant positive association with FEV₁.

The adjusted mean FVC according to the adiposity measures is shown in Figure 2. Mean FVC was significantly lower in obese men than in each of the other BMI groups (all: P < 0.05). A significant inverse association was seen with WC, WHR, and %BF. FVC was lower only in men in the top distribution of FM; this is a pattern similar to that seen for BMI. FFM showed weak and nonsignificant positive associations with FVC after adjustment for confounders. The inverse relations between adiposity measures (ie, WHR, WC, FM, and %BF) and FEV₁ and FVC remained significant after adjustment for BMI. Because FFM was positively associated with BMI, adjustment for BMI strengthened the positive association between FFM and FVC. Although the linear trend was not significant (P = 0.10), there were significant overall differences between the groups (P = 0.02, F test for 4 df), and those with low FFM (< 43.27) had significantly lower FVC than did the rest (3.39 and 3.55, respectively; P < 0.0001). Exclusion of current smokers and men who had stopped smoking within the previous 2–4 y made little difference to the pattern of relations seen between lung function and measures of adiposity.
FVC: $P = 0.03$; both: test for interaction) (data not shown). No significant interaction was seen between BMI and the adiposity measures (ie, %BF, WHR, and FFM) for either FEV\textsubscript{1} or FVC.

We examined relations between measures of adiposity and mean FEV\textsubscript{1}:FVC values and the risk of having a low FEV\textsubscript{1}:FVC (ie, < 70%). After adjustment for age, socioeconomic group, physical activity, alcohol intake, and smoking, only BMI and FFM were significantly associated with FEV\textsubscript{1}:FVC, and only the significant associations with BMI and FFM are shown in Table 4. Higher BMI was associated with higher FEV\textsubscript{1}:FVC, and the odds of having a low FEV\textsubscript{1}:FVC (airway obstruction) tended to decrease with increasing BMI. Increasing FFM was associated with increasing mean FEV\textsubscript{1}:FVC and reduced odds of a low FEV\textsubscript{1}:FVC. Because higher BMI is associated with higher muscle mass and lower BMI is associated with weight loss and respiratory disease, we further adjusted for FFM and excluded men with respiratory problems or weight loss. The inverse association between BMI and FEV\textsubscript{1}:FVC, although weakened, remained significant ($P = 0.02$).

**DISCUSSION**

In the current large study of men aged 60–79 y, FEV\textsubscript{1} was reduced only in lean and obese men, but an inverse association was seen between BMI and FVC. FM, %BF, and central adiposity (ie, WHR and WC) correlated negatively with lung function, whereas FFM, which reflects increased muscle mass, correlated positively with lung function. These associations, although modest, remained significant even after adjustment for potential confounders, including age, smoking, and physical activity. Our findings complement and extend previous reports (6–10) by simultaneously examining the effects of body composition and several indicators of body fat and fat distribution on lung function measures (FEV\textsubscript{1}, FVC, and FEV\textsubscript{1}:FVC) in a large elderly population study.

**Body composition, body fat distribution, FEV\textsubscript{1}, and FVC**

Higher BMI is associated with both increased FM and muscle mass (ie, FFM), which have been shown to have opposite effects on lung function in this and other studies (6, 7, 10). Previous studies of the relation of body composition to lung function produced inconsistent results (6–10). Whereas most studies have reported that FFM is positively associated with lung function (6–10) some have failed to find any association between FM and lung function (8, 9), possibly because of the limited ability of the small sample to detect a difference when the effects are modest or concentrated at particularly high amounts of FM. It has been suggested that marked degrees of adiposity may be needed for adiposity to have an effect on pulmonary function (9). However, we have shown that the effect of body fat and body fat distribution on lung function, although modest, is not limited to obese...
Fat-free mass (kg) than WC) showed the strongest correlation with both FEV₁ and mechanisms remain uncertain (33). The reason that WHR (rather expected on the basis of reduced lung volume alone, although the be related to a greater degree of airway narrowing than would be distribution of blood to the thoracic compartment that reduces vital (15). In addition, high amounts of FM and adiposity may (imparting the possibility that abdominal fat deposition leads to a redis- result of several mechanisms. Abdominal fat deposition may (12, 16). With increasing obesity, fat deposition in men tends to occur centrally (both around the trunk and intraabdominally); this pattern of central fat deposition is likely to be particularly important in influencing lung function. The importance of central fat deposition may explain the more apparent effect of FM on lung function in the overweight and obese men but not in the lean men, in whom central fat deposition is less marked. Our findings that both WC and (to a greater extent) WHR (both indicators of central adiposity) showed significant inverse relations with lung function (ie, FEV₁ and FVC) is in keeping with the importance of central adiposity and is consistent with the results of other population studies (6, 7, 10–16). The stronger association of BMI, WC, and FM with FVC than with FEV₁ is consistent with a primarily restrictive pattern on lung function, which could be the result of several mechanisms. Abdominal fat deposition may directly impede the descent of the diaphragm, whereas fat depo- position in the chest wall may diminish rib cage movement and thoracic compliance, both of which lead to restrictive respiration impairment (5). Other mechanisms have been suggested, including the possibility that abdominal fat deposition leads to a redis- tribution of blood to the thoracic compartment that reduces vital capacity (15). In addition, high amounts of FM and adiposity may be related to a greater degree of airway narrowing than would be expected on the basis of reduced lung volume alone, although the mechanisms remain uncertain (33). The reason that WHR (rather than WC) showed the strongest correlation with both FEV₁ and FVC is uncertain. It is possible that increased WHR reflects both increased abdominal fat and reduced muscle mass, as quantified by hip circumference (34), and that both components contribute to decreased lung function.

**Fat-free mass**

Despite various studies’ different methods of calculating FM and FFM (muscle mass), most studies have shown FFM to be associated with increased lung function (6–10). Greater amounts of FFM may be associated with physical activity, which tends to be associated with higher lung function in the elderly (8). However, the association was independent of physical activity. In a large population study of elderly Japanese American men (aged 71–93 y), although body composition was not measured, grip strength correlated positively with FEV₁ and FVC (13). This suggests that the effects of FFM on lung function may be asso- ciated with stronger respiratory musculature (35). In the current study, the exclusion of men with COPD, as indicated by FEV₁: FVC and weight loss, attenuated the positive association be- tween FFM and FEV₁, and lung function was lowered only in those with low FFM. However, BMI < 22.5 was not associated with low FEV₁, after exclusions, which suggests that low FMM may have a specific relation with low FEV₁. This could be a direct reflection of diminished respiratory muscle mass, though the mechanism remains uncertain.

**FEV₁:FVC**

Restrictive lung disease (ie, lung fibrosis or physical deformities) is characterized by low FVC but normal or high FEV₁:FVC, whereas obstructive lung disease (ie, asthma, bronchitis, or em- physema) is characterized by low FEV₁ and a low FEV₁:FVC. The inverse association between FFM and FEV₁ and the FEV₁: FVC suggests that low muscle mass is more closely associated with obstructive lung disease, whereas FM and central adiposity, which showed no associations with FEV₁:FVC, are more likely to be associated with restrictive lung patterns. The lack of associa- tion of body fat and fat distribution with a low FEV₁:FVC suggests that body fat distribution has no significant effect on air flow rate; this possibility is consistent with findings from the third National Health and Nutrition Examination Survey, which suggested no association between obesity and air flow obstruc- tion (34). Our finding that BMI was positively associated with FEV₁:FVC has also been reported in other US studies (12, 36).

**Strengths and limitations**

Adiposity variables were directly measured in this study and are not subject to reporting bias. Although the findings from the current study are based on 77% of survivors, the mean BMIs of those who presented for rescreening and of nonattenders had been almost identical at initial screening, although subjects in ill
health were less likely to attend the rescreening (37). However, this underrepresentation of subjects in ill health is unlikely to affect the relations seen between the adiposity measures and lung function, because all men with CVD or diabetes were excluded. The cross-sectional nature of this study precludes definitive causal inference about the relation of body composition and fat distribution to lung function. However, longitudinal studies have shown that weight reduction significantly slowed the decline in lung function (38, 39), although the modest size of the observed effects of adiposity on lung function suggests that other factors, particularly the loss of pulmonary elastic tissue, are important (40). Bioelectric impedance analysis to estimate FM and FFM was based on the equation of Deurenberg et al (23), which has been validated in an elderly population. Previous studies noted inaccuracies in the use of bioelectric impedance analysis to assess FFM in the elderly (41, 42), and there was some within-subject variation for FFM. Thus, estimates of FFM (a surrogate measure of muscle mass) may be subject to imprecision and may not accurately reflect muscle mass. However, because imprecision tends to bias the results toward the null hypothesis, the true magnitude of association between FFM and lung function is likely to have been underestimated. Finally, we cannot necessarily generalize our findings to other ethnic groups or to women. Whereas some previous studies suggested that the relations of adiposity and lung function are broadly similar in men and women (14), others reported that the associations between body fat distribution and lung function are considerably stronger in men (15).

Conclusions

Body composition and body fat distribution are significant determinants of lung function in elderly men. The data in the current study suggest opposite effects on lung function by central adiposity and FM (inverse effect) and muscle mass (positive effect). This possibility has important implications for assessments of the effects of weight on lung function.

SGW and AGS contributed to the idea and analysis and drafted the manuscript. AGS designed the original study, and PHW was responsible for the 20-y rescreening of the study population. All authors contributed to the writing of the manuscript. None of the authors had any personal or financial conflict of interest.

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