Effects of body composition and fat distribution on ventilatory function in adults\textsuperscript{1,2}

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\section*{ABSTRACT} Clinically, gross obesity is associated with disturbances of ventilatory function, but less severe obesity is not generally thought to have a significant effect on ventilatory function. The purpose of this report was to examine cross-sectional data to determine the effects of body composition and fat distribution on ventilatory function in 1235 adults (621 men and 614 women). Forced vital capacity (FVC) was used as a measure of ventilatory function and was adjusted for age, height, smoking, and bronchial symptoms in separate models for men and women. Body fat and fat-free mass were estimated from skinfold-thickness measurements. Adjusted FVC was not significantly associated with body mass or body mass index, but was negatively associated with percentage body fat in men ($P = 0.0003$) and women ($P = 0.043$) and positively associated with fat-free mass in men ($P = 0.018$) and women ($P = 0.0001$). Handgrip strength was positively associated with adjusted FVC in both sexes ($P < 0.02$), suggesting that the effect of fat-free mass may be mediated by muscular strength. Adjusted FVC was negatively associated with subscapular-skinfold thickness in both sexes ($P < 0.0003$) and with waist circumference ($P = 0.01$) and waist-to-hip ratio ($P = 0.03$) in men. Previous reports that considered only body mass index or body mass failed to distinguish the opposing effects of fat-free mass and fat mass on FVC. Am J Clin Nutr 1998;68:35–41.

\section*{KEY WORDS} Respiratory function tests, body composition, body fat, fat-free mass, handgrip strength, forced vital capacity, spirometry, adults, humans

\section*{INTRODUCTION} The inventor of the spirometer, John Hutchinson, found that height, age, and disease were the major determinants of ventilatory function in the 2130 men he examined (1). Hutchinson also noted that after taking height into account, vital capacity increased steadily with increasing mass up to a certain point and then began to decrease among the most grossly overweight (1).

Although impairment of ventilatory function is now widely recognized among grossly obese individuals (2, 3), less is known about milder forms of obesity or the effects of regional fat distribution in population samples. Studies concerned with healthy reference values for ventilatory function have generally reported weak or nonsignificant associations with body mass or body mass index (BMI) after accounting for the effects of age and height in linear regression models (4).

One simple model of body composition divides the body mass into 2 compartments: fat mass, consisting of all of the fat in the body, and fat-free (or lean) mass (FFM), consisting of everything else (5). The importance of the size of the fat mass and the distribution of body fat (6) has been recognized in a range of chronic diseases, including cardiovascular disease and abnormalities of glucose tolerance (diabetes and insulin resistance) (7). FFM has been associated with immune competence, functional status, and survival (8).

Relatively few previous reports have considered regional fat distribution or fat mass and FFM separately in relation to ventilatory function. There have been 2 reports that the central (or upper body) pattern of fat distribution is negatively associated with ventilatory function in adults (9, 10). However, these results were from nonrandom samples that included no women. Similar findings were reported from a random population sample of schoolchildren (11).

The purpose of this report was to extend the findings of previous studies by exploring the independent effects of body composition and fat distribution pattern on ventilatory function in a relatively large sample of adults over a wide age range because clarification and wider recognition of yet another adverse consequence of excess adiposity may be important both for public health and clinical practice.

\section*{SUBJECTS AND METHODS} Subjects

Subjects for the 1990 Pilot Survey of the Fitness of Australians were selected from the adult population (age range: 18–78 y) of metropolitan Adelaide, South Australia, by using a randomized 3-stage sampling procedure, which was described in detail previously (12). Informed consent was obtained from all

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participants \(n = 2298\), who were interviewed at home about their cigarette smoking habits, health, and physical activity. A subsample \(n = 1235\) who also agreed to participate in a laboratory-based physical examination, spirometry, and fitness testing provided the data reported here. The project was approved by the Human Ethics Committee of the University of Adelaide and all subjects provided informed consent before participating.

**Measurements**

Details of the sampling, spirometry, and definition of bronchial symptom status were reported in detail elsewhere (13). Briefly, flow-volume loops were recorded in accordance with American Thoracic Society recommendations (14) with a pneumotachograph that was regularly calibrated throughout the testing period. Seated subjects wearing nose clips performed maximal forced expiratory efforts until 3 flow-volume loops were within 3% of each other. The largest volume from a technically satisfactory trial was recorded as the forced vital capacity (FVC) and was corrected to body temperature and pressure, saturated with water vapor. The presence of any 1 of 8 bronchial symptoms that were found previously to be associated with diminished ventilatory function were used to define symptomatic subjects (13). Questionnaires on lifetime tobacco habits were used to determine the smoking status for each subject. Subjects who had a lifetime total of 1 pack-year equivalent were defined as exsmokers. Subjects who currently used tobacco regularly were defined as current smokers.

Anthropometric measures, including height, weight, waist and hip girths, handgrip strength, and skinfold thicknesses from 6 sites (biceps, triceps, subscapular, midabdominal, supraspinal, and medial calf) were obtained by trained observers using standard methods and regularly calibrated equipment (12). Subscapular-skinfold thickness was used as a measure of chest wall fat. Both waist girth and the ratio of waist girth to hip girth (or waist-to-hip ratio; WHR) were used as measures of body fat distribution. BMI was calculated as mass (kg) divided by height squared (m). Estimates of percentage body fat (\%BF) were calculated according to the method suggested by Frisancho (15) in which age- and sex-specific equations are used to predict body density from skinfold-thickness measurements (16). Fat mass was estimated as follows: fat mass = weight \times \%BF/100. FFM was calculated as the difference between measured body mass and predicted fat mass.

**Statistical analysis**

To test for participation bias, unpaired \(t\) tests were used to compare age and self-reported height and weight (and BMI calculated from self-reported height and weight) between subjects who agreed to undergo spirometry and anthropometry and who completed questionnaires only. Analysis of variance (ANOVA) was used to test for significant differences in unadjusted, continuously measured characteristics between quintiles of FVC, separately for each sex.

To examine the effects of body composition and fat distribution on FVC, models were tested for each sex separately by using the SAS (17) generalized linear modeling procedure (PROC GLM). Separate models were tested for each measure of body composition (body mass, BMI, \%BF, and FFM). In each of these models, least-squares-adjusted mean FVC was calculated for each quintile of the body-composition measure. In all models, mean FVC values were adjusted for age, age squared, height, bronchial symptoms, and smoking status by inclusion of these as terms in the model. The quadratic term on age squared was added to all models because it improved the visual impression of linearity in plots of residuals by age. Smoking status was represented by 2 mutually exclusive binary indicator terms—one for subjects who were current smokers and the other for subjects who were exsmokers. Note that measured height and weight are shown because they were available for all subjects. Subjects in the lower quintiles for FVC were shorter, were older, were more obese, had a more central distribution of fat, and had lower handgrip strength than those in higher quintiles. These differences were significant at \(P < 0.0001\) by ANOVA for all variables except waist circumference in men \((P = 0.44)\) and weight in men \((P = 0.002)\) and women \((P = 0.56)\).

The relation between FVC (adjusted for age, height, bronchial symptoms, current smoking, and exsmoking) and BMI for men and women separately is shown in Figure 1. The difference in the mean FVC between the lowest and the highest quintiles was not significant \((P = 0.98\) for men and 0.93 for women). Similar results were obtained when weight was used instead of BMI (Figure 2).
The relation between mean adjusted FVC and quintile of %BF is shown in Figure 3. FVC was significantly lower in the highest quintile than in the lowest quintile (P = 0.0003 for men and P = 0.043 for women). A trend is seen in the intermediate quintiles, lending further support to the conclusion that increasing proportions of body fat are associated with decreasing FVC. No significant increase in FVC with increasing FFM quintile was found (P = 0.070 for men and P = 0.71 for women) until additional adjustment for %BF by adding %BF to the model (P = 0.018 for men and P = 0.0001 for women) as illustrated in Figure 4. Increasing FVC was associated with increased handgrip strength (P = 0.019 for men and P = 0.0001 for women; Figure 5).

Adjusted FVC by quintile of subscapular-skinfold thickness was significantly different between the low and high quintiles (P = 0.0003 for men and P = 0.0001 for women; Figure 6). Adjusted FVC by waist girth quintile was significantly different between the low and high quintiles for men (P = 0.010) but not for women (P = 0.84) (Figure 7). A similar pattern is seen for WHR in Figure 8; the difference between the low and high quintiles was significant for men (P = 0.031) but not for women (P = 0.98).

All analyses were repeated by using only data from asymptomatic lifelong nonsmokers (n = 560) (12). The same pattern of associations was seen, but the smaller sample size gave a wider range of CIs (data not shown). All analyses were repeated by using only subjects who were exsmokers and again by using only current smokers because body fat and fat distribution may be influenced by smoking status. Again, the patterns of association in the 2 strata were essentially the same as in the present study, although the smaller number of subjects in each stratum increased the width of the CIs (results not shown). These findings suggest that smoking status was not an important effect modifier of the relation between body composition and ventilatory function.

**DISCUSSION**

**Major findings**

In an unadjusted ANOVA by FVC quintile, there were significant differences in both fat mass and FFM and in measures of body fat distribution in both men and women. In multivariable analyses, no significant linear relation between body mass or BMI and FVC was found after adjustment for height, age, bronchial symptoms, and smoking status. However, there was a significant negative association between %BF and adjusted FVC. No significant association between FFM and adjusted FVC was found until %BF was adjusted for, at which time the relation became significant and positive. Because body mass does not distinguish between fat mass and FFM, the curvilinear relations suggested in Figures 1 and 2 (originally reported by Hutchinson (1) for body mass) probably arose as a result of the combination of opposing effects from these 2 separate body components.

Subscapular-skinfold thickness was significantly associated with decreased FVC in both sexes. A significant association between a central pattern of fat distribution and decreased ventilatory function was found in men only, using either waist circumference or WHR. In all cases, the effects we found were relatively small from a clinical perspective, amounting to a difference of

### TABLE 1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>FVC quintile</th>
<th>FVC</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>BMI</th>
<th>Waist girth</th>
<th>WHR</th>
<th>Subscapular-skinfold thickness</th>
<th>Fat mass</th>
<th>Fat-free mass</th>
<th>Handgrip strength</th>
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<tbody>
<tr>
<td>L (cm)</td>
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</tr>
<tr>
<td>1 (n = 125)</td>
<td>3.52 ± 0.44</td>
<td>59.7</td>
<td>12.02</td>
<td>169.7 ± 6.28</td>
<td>75.9 ± 11.42</td>
<td>26.3 ± 3.34</td>
<td>96.2 ± 9.22</td>
<td>0.96 ± 0.05</td>
<td>21.0 ± 8.73</td>
<td>29.1 ± 6.17</td>
<td>53.5 ± 6.22</td>
<td>40.5 ± 7.11</td>
</tr>
<tr>
<td>2 (n = 125)</td>
<td>4.29 ± 0.15</td>
<td>52.0</td>
<td>12.11</td>
<td>173.2 ± 5.30</td>
<td>78.2 ± 10.39</td>
<td>26.0 ± 3.26</td>
<td>94.3 ± 9.82</td>
<td>0.94 ± 0.06</td>
<td>19.6 ± 8.16</td>
<td>27.5 ± 5.94</td>
<td>56.2 ± 5.49</td>
<td>44.3 ± 6.94</td>
</tr>
<tr>
<td>3 (n = 123)</td>
<td>4.79 ± 0.14</td>
<td>43.2</td>
<td>12.86</td>
<td>175.5 ± 5.48</td>
<td>77.7 ± 11.50</td>
<td>25.2 ± 3.36</td>
<td>91.1 ± 10.57</td>
<td>0.92 ± 0.06</td>
<td>16.9 ± 7.47</td>
<td>24.9 ± 6.45</td>
<td>58.1 ± 5.78</td>
<td>49.2 ± 6.58</td>
</tr>
<tr>
<td>4 (n = 124)</td>
<td>5.30 ± 0.15</td>
<td>37.4</td>
<td>11.35</td>
<td>178.0 ± 5.39</td>
<td>79.8 ± 11.73</td>
<td>25.2 ± 3.09</td>
<td>97.2 ± 8.23</td>
<td>0.89 ± 0.06</td>
<td>15.6 ± 7.11</td>
<td>22.8 ± 5.61</td>
<td>61.1 ± 7.18</td>
<td>51.0 ± 7.56</td>
</tr>
<tr>
<td>5 (n = 125)</td>
<td>6.12 ± 0.50</td>
<td>34.8</td>
<td>10.61</td>
<td>182.0 ± 5.93</td>
<td>81.3 ± 10.74</td>
<td>24.6 ± 2.91</td>
<td>89.5 ± 10.24</td>
<td>0.89 ± 0.06</td>
<td>14.2 ± 7.04</td>
<td>21.5 ± 5.44</td>
<td>63.7 ± 5.80</td>
<td>52.0 ± 8.07</td>
</tr>
</tbody>
</table>

All (n = 621) 4.80 ± 0.94 45.5 ± 15.01 175.7 ± 7.04 78.6 ± 11.28 25.5 ± 3.25 93.7 ± 37.83 0.92 ± 0.07 17.5 ± 8.10 25.3 ± 6.57 58.4 ± 7.05 47.4 ± 8.46

\[ ^{1} \text{SD.} \text{FVC, forced vital capacity; WHR, waist-to-hip ratio.} \]

\[ ^{2} \text{Means significantly different between FVC quintiles,} \ P < 0.0001 \ (\text{ANOVA}). \]

### TABLE 2

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>FVC quintile</th>
<th>FVC</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>BMI</th>
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</tr>
<tr>
<td>1 (n = 122)</td>
<td>2.52 ± 0.26</td>
<td>60.9</td>
<td>10.75</td>
<td>157.8 ± 5.83</td>
<td>64.9 ± 12.24</td>
<td>26.0 ± 4.51</td>
<td>86.1 ± 13.58</td>
<td>0.85 ± 0.08</td>
<td>22.2 ± 9.36</td>
<td>38.8 ± 5.48</td>
<td>39.4 ± 5.50</td>
<td>25.0 ± 4.97</td>
</tr>
<tr>
<td>2 (n = 125)</td>
<td>3.11 ± 0.13</td>
<td>48.7</td>
<td>11.89</td>
<td>160.8 ± 6.03</td>
<td>64.9 ± 13.15</td>
<td>25.1 ± 4.98</td>
<td>82.0 ± 11.87</td>
<td>0.81 ± 0.07</td>
<td>21.6 ± 10.17</td>
<td>37.4 ± 6.30</td>
<td>40.2 ± 5.64</td>
<td>27.7 ± 4.46</td>
</tr>
<tr>
<td>3 (n = 123)</td>
<td>3.48 ± 0.10</td>
<td>42.4</td>
<td>11.69</td>
<td>162.2 ± 4.94</td>
<td>65.5 ± 13.53</td>
<td>24.9 ± 4.63</td>
<td>80.5 ± 12.26</td>
<td>0.79 ± 0.07</td>
<td>20.0 ± 10.24</td>
<td>35.1 ± 6.51</td>
<td>42.1 ± 6.00</td>
<td>30.1 ± 4.29</td>
</tr>
<tr>
<td>4 (n = 121)</td>
<td>3.82 ± 0.11</td>
<td>38.0</td>
<td>11.66</td>
<td>165.2 ± 4.58</td>
<td>65.1 ± 11.24</td>
<td>23.8 ± 3.79</td>
<td>78.4 ± 11.24</td>
<td>0.78 ± 0.06</td>
<td>17.4 ± 9.25</td>
<td>33.2 ± 6.82</td>
<td>43.1 ± 4.77</td>
<td>30.2 ± 5.19</td>
</tr>
<tr>
<td>5 (n = 123)</td>
<td>4.42 ± 0.39</td>
<td>34.7</td>
<td>9.73</td>
<td>169.2 ± 6.27</td>
<td>67.2 ± 10.21</td>
<td>23.5 ± 3.27</td>
<td>79.1 ± 9.75</td>
<td>0.78 ± 0.06</td>
<td>16.2 ± 7.80</td>
<td>31.5 ± 6.09</td>
<td>45.5 ± 5.31</td>
<td>33.0 ± 5.18</td>
</tr>
<tr>
<td>All (n = 614)</td>
<td>3.47 ± 0.68</td>
<td>44.9</td>
<td>14.47</td>
<td>163.0 ± 6.78</td>
<td>65.5 ± 12.13</td>
<td>24.7 ± 4.37</td>
<td>81.2 ± 12.08</td>
<td>0.80 ± 0.07</td>
<td>19.5 ± 9.69</td>
<td>35.3 ± 6.78</td>
<td>42.0 ± 5.85</td>
<td>29.2 ± 5.52</td>
</tr>
</tbody>
</table>

\[ ^{1} \text{SD.} \text{FVC, forced vital capacity; WHR, waist-to-hip ratio.} \]

\[ ^{2} \text{Means significantly different between FVC quintiles,} \ P < 0.0001 \ (\text{ANOVA}). \]
<8% or less in mean adjusted FVC between the lowest and highest quintiles.

Limitations

Body composition was estimated in this report by using published regression equations based on skinfold-thickness measurements. These predicted values are likely to be associated with greater measurement error than those with use of more direct measures of body composition, but the techniques available (eg, hydrostatic densitometry or dual-energy X-ray absorptiometry) are not feasible for large samples. Similarly, the measures of body fat distribution available were relatively crude and associated with measurement error.

We are not aware of any evidence to suggest that measurement error in the estimates of body composition or of fat distribution for an individual might be associated with the outcome of interest (FVC) in this report and believe that measurement error is not an explanation for our findings. If the measurement error associated with the prediction equations was distributed randomly between subjects, the effect would likely have been a bias toward the finding of no association. As a result, the true magnitude of the associations is likely to be greater than reported here.

Survey respondents who did not undergo spirometry were excluded from the results presented here. Female participants were slightly taller than this excluded group, but there were no other significant differences in self-reported height, weight, or BMI. Self-reported height and weight are known to be biased compared with measurements, so participants may have differed from those who declined to participate in terms of ventilatory function or in more subtle aspects of body composition. In addi-
tion, our findings may have been influenced by participation bias because only 54% of the random population sample participated in the physical examination and spirometry.

Body mass and ventilatory function

The literature on reference ranges for spirometry in healthy individuals is extensive. In studies in which body mass was considered, most authors [eg, Ferris et al (18) and Knudson et al (19)] reported no association between body mass and ventilatory function after accounting for age and height. Some of the larger studies have found that although body mass has a detectable effect on ventilatory function, the additional variance explained by mass (or BMI) in linear regression models was modest in both adults (4) and children (20).

Given these findings, it has generally been agreed that prediction equations based on height and age are satisfactory. In nearly all cases, the decision not to include mass was based on simple correlation or linear regression coefficients. As Hutchinson (1) reported in men, we found that the association between mass and FVC in both sexes seemed to follow a curvilinear pattern and there was a similar relation for BMI in our data. Nonsignificant correlation and linear regression coefficients would be expected from the relations shown in Figures 1 and 2.

A slightly more sophisticated approach separates total body mass into 2 components: FFM and fat mass. Our findings show that these components had opposite effects on FVC, which probably explains why previous investigators found no effect or relatively small effects from measures such as BMI or body mass. It seems likely that additional improvements in prediction equa-

![FIGURE 5](https://example.com/figure5.png)

**FIGURE 5.** Adjusted forced ventilatory capacity (FVC) by quintile of handgrip strength for men and women separately. Error bars show the 95% CI around the mean. \( P \) for difference between top and bottom quintiles = 0.019 for men and 0.0001 for women.

![FIGURE 6](https://example.com/figure6.png)

**FIGURE 6.** Adjusted forced ventilatory capacity (FVC) by quintile of subscapular-skinfold thickness for men and women separately. Error bars show the 95% CI around the mean. \( P \) for difference between top and bottom quintile = 0.0003 for men and 0.0001 for women.

![FIGURE 7](https://example.com/figure7.png)

**FIGURE 7.** Adjusted forced ventilatory capacity (FVC) by quintile of waist girth for men and women separately. Error bars show the 95% CI around the mean. \( P \) for difference between top and bottom quintile = 0.010 for men and 0.84 for women.

![FIGURE 8](https://example.com/figure8.png)

**FIGURE 8.** Adjusted forced ventilatory capacity (FVC) by quintile of waist girth-to-hip girth ratio for men and women separately. Error bars show the 95% CI around the mean. \( P \) for difference between top and bottom quintile = 0.031 for men and 0.98 for women.
tions for ventilatory function could result from more detailed consideration of the effects of body composition and this may be a subject worthy of further research.

Fat and ventilatory function

The negative association between fat mass and FVC in this population sample confirms that the effect of body fat on ventilatory function is not limited to extremely obese individuals. The explanation for this association is not entirely clear, but it seems plausible that fat deposits could have mechanical effects on ventilatory function. However, fat is a metabolically active tissue (6) and our data do not exclude the possibility of metabolic effects.

The finding of a significant effect among men of waist circumference lends support to the possibility that a large abdominal fat mass might impede descent of the diaphragm during forced inspiration, although this was not seen in women in the present study. Similarly, the significant negative effect associated with subcapsular-skinfold thickness suggests that a thick layer of subcutaneous fat over the chest wall may lead to a change in the balance of elastic recoil between the chest wall and the lung parenchyma or to changes in chest wall compliance.

FFM and ventilatory function

Forced inspiration requires muscular contraction to overcome air pressure on the large surface area of the chest wall (1). An association between respiratory muscle strength and ventilatory function was reported previously among older subjects (21). Significant positive correlations \( r = 0.2–0.4 \) between handgrip strength and FVC were found across all age strata in both sexes among the Framingham cohort (22), suggesting that the association was independent of age and sex. After adjustment for age and height, a positive correlation \( r = 0.15 \) was reported between handgrip strength and forced expiratory volume in 1 s in the Honolulu Heart Study cohort (23). These findings from other populations are consistent with the results reported here.

Although we did not have specialized measures of respiratory muscle strength available, consistent reporting of a significant association between handgrip strength and FVC suggests that more muscle mass may at least partially explain the association between FVC and FFM, given that muscle tissue mass is counted in the FFM compartment.

Inclusion of smokers and symptomatic subjects

A previous study of the sample reported here found a significant decrease in FVC among exsmokers and subjects with bronchial symptoms (13). These associations were also found in most other populations studied. As a result of these negative associations, it has become common practice to exclude smokers, exsmokers, and symptomatic subjects from studies of factors influencing ventilatory function to avoid confounding. However, there are 3 arguments in favor of including smokers and symptomatic participants (with appropriate adjustment in the models) in this report. First, the patterns of association were not altered when analysis was restricted to asymptomatic lifelong nonsmokers or to specific smoking status groups although the smaller sample sizes in each of these strata resulted in a wider range of CIs for estimates of effect. Second, the SEs in each quintile were smaller because of the larger sample size, so our estimates of effect (in terms of differences between lowest and highest quintile means) were more precise. Third, the results presented here are probably generalizable to populations of similar, developed countries rather than to asymptomatic lifelong nonsmokers.

Interpretation

Previous reports that failed to distinguish fat from FFM have resulted in an underestimation of the importance of body composition as a factor influencing ventilatory function. As reported previously in schoolchildren and men, higher levels of body fat were associated with decreased ventilatory function in the adults in the present study. Widely used but crude indexes of obesity such as body mass or BMI did not adequately distinguish between fat mass and FFM. The positive association between FFM and FVC may have been mediated by muscle strength and it seems likely that the negative association between fat mass and FVC was at least partially due to mechanical effects. Our findings are of clinical and public health importance because they suggest that impaired ventilatory function should be added to the already long list of adverse consequences of excess adiposity.

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