Body mass index and waist circumference independently contribute to the prediction of nonabdominal, abdominal subcutaneous, and visceral fat1–3

Ian Janssen, Steven B Heymsfield, David B Allison, Donald P Kotler, and Robert Ross

ABSTRACT

Background: It is unknown whether the ability of waist circumference (WC) to predict health risk beyond that predicted by body mass index (BMI) alone is explained in part by the ability of WC to identify those with elevated concentrations of total or abdominal fat.

Objective: We sought to determine whether BMI and WC independently contribute to the prediction of nonabdominal (total fat — abdominal fat), abdominal subcutaneous, and visceral fat.

Design: Fat distribution was measured by magnetic resonance imaging in 341 white men and women. Multiple regression analysis was performed to measure whether the combination of BMI and WC explained a greater variance in nonabdominal, abdominal subcutaneous, and visceral fat than did BMI or WC alone. These fat depots were also compared after a subdivision of the cohort into 3 BMI (normal, overweight, and class I obese) and 3 WC (low, intermediate, and high) categories according to the classification system used to identify associations between BMI, WC, and health risk.

Results: Independent of age and sex, the combination of BMI and WC explained a greater variance in nonabdominal, abdominal subcutaneous, and visceral fat than did either BMI or WC alone (P < 0.05). For nonabdominal and abdominal subcutaneous fat, BMI was the strongest correlate; thus, by adding BMI to WC, the variance accrued was greater than when WC was added to BMI. However, when WC was added to BMI, the added variance explained for visceral fat was greater than when BMI was added to WC. Furthermore, within each of the 3 BMI categories studied, an increase in the WC category was associated with an increase in visceral fat (P < 0.05).

Conclusions: BMI and WC independently contribute to the prediction of nonabdominal, abdominal subcutaneous, and visceral fat in white men and women. These observations reinforce the importance of using both BMI and WC in clinical practice.


KEY WORDS Body mass index, waist circumference, body fat, abdominal fat, visceral fat

INTRODUCTION

Population-based, cross-sectional (1, 2), and prospective (3–6) studies clearly establish that body mass index (BMI) and waist circumference (WC) are predictors of cardiovascular disease and type 2 diabetes. In addition, WC remains a significant predictor of disease after control for the disease risk predicted by BMI (3–7). The latter observation is consistent with a large body of evidence implicating abdominal obesity, in particular visceral fat, in the pathogenesis of numerous metabolic risk factors (8–10). The fact that elevated WC values add to the risk of disease predicted by BMI alone is recognized within the classification system proposed by the National Institutes of Health to identify the relative health risk associated with overweight and obesity (11). Indeed, for BMI (in kg/m2) values ranging from 18.5 to 34.9, men and women with high WC values are considered to be at a greater relative health risk than those with low WC values (11).

Although the mechanisms that explain the increased health risk predicted by WC are not firmly established, it is often suggested that the added risk is explained by the metabolic complications associated with elevations in abdominal obesity (11, 12). If this is true, then those within a given BMI category (eg, class I obesity, BMI: 30.0–34.9) with high WC values should have greater accumulations of abdominal subcutaneous or visceral fat than those with low WC values. To our knowledge there is no evidence that provides direct support for this assumption. Confirmation that BMI and WC independently contribute to the prediction of total and abdominal obesity would add to our understanding of the potential mechanisms by which elevated WC values predict disease.

1From the School of Physical and Health Education, Queen’s University, Kingston, Canada (IJ and RR); the Obesity Research Center, St Luke’s–Roosevelt Hospital, Institute of Human Nutrition, Columbia University, College of Physicians and Surgeons, New York (SBH, DBA, and DPK); and the Department of Biostatistics and Center for Research on Clinical Nutrition, University of Alabama at Birmingham (DBA).

2Supported in part by grants from the Canadian Institutes of Health Research (MT 13448) and the Natural Sciences and Engineering Research Council of Canada Grant (OGPIN 030) to RR; grants from the National Institutes of Health to SBH (RR-00645 and DK-42618) and DBA (P30DK56336); and a Trainee Award from the Heart and Stroke Foundation of Canada Research to IJ.

3Address reprint requests to R Ross, School of Physical and Health Education, Queen’s University, Kingston, Ontario, Canada, K7L 3N6. E-mail: rossr@post.queensu.ca.

Received January 18, 2001.
Accepted for publication May 18, 2001.
Therefore, the purpose of this investigation was to determine whether BMI and WC independently contribute to the prediction of total, nonabdominal, abdominal subcutaneous, and visceral fat. To do so we measured total and regional fat distribution by magnetic resonance imaging (MRI) in 341 white men and women varying widely in age and adiposity.

**SUBJECTS AND METHODS**

**Subjects**

The subjects were healthy white men (n = 206) and women (n = 135) who had participated in body composition studies at Queen’s University (Kingston, Canada) and St Luke’s–Roosevelt Hospital (New York). The subjects varied in age (18–88 y) and adiposity (BMI: 15.9–47.7). One hundred ninety-eight subjects were studied in Kingston and 143 subjects were studied in New York. Subjects were recruited from among hospital employees, from students at local universities, and from the general public through posted flyers and the local media. All participants gave informed consent before participation in accordance with the ethical guidelines of the respective institutional review boards.

**Measurement of total and regional fat by magnetic resonance imaging**

At both the Kingston and New York laboratories, whole-body (=41 equidistant images) MRI data were obtained with a 1.5-Tesla magnet (General Electric, Milwaukee, WI) by using an established protocol described in detail elsewhere (13, 14). Once acquired, the MRI data were transferred to standalone workstations (Silicon Graphics, Mountain View, CA) for analysis by using specially designed computer software (SLICE-O-MATIC, version 3.0; TomoVision Inc, Montreal), the procedures for which are described elsewhere (13, 15). Total fat (subcutaneous + visceral + intrapelvic + intrathoracic + intermuscular) was determined by using all 41 images. Visceral fat and abdominal subcutaneous fat were calculated by using 5 images extending from 5 cm below L4–L5 to 15 cm above L4–L5. Abdominal fat was calculated by adding abdominal subcutaneous and visceral fat. Nonabdominal fat was calculated by subtracting abdominal fat from total fat. Fat volume units (in L) were converted to mass units (in kg) by multiplying the volumes by the assumed constant density for adipose tissue (0.92 kg/L) (16).

We previously reported that the mean differences for repeated measurements of total, abdominal, and visceral fat are 2.6%, 3.0%, and 5.5%, respectively (14). The repeatability was calculated by comparing one observer’s analysis of 2 separate MRI acquisitions in 3 subjects. The reproducibility of MRI measurements across the laboratories was determined by comparing 2 observers (each from a different laboratory) analysis of the same MRI images for 5 subjects. The interlaboratory difference was 1.1%, 1.4%, 1.1% for total, abdominal subcutaneous, and visceral fat, respectively.

**Anthropometric measurements**

Body mass was measured to the nearest 0.1 kg while subjects were dressed in light clothing. Subjects stood barefoot while height was measured to the nearest 0.5 cm by using a wall-mounted stadiometer (Holtain Ltd, Crymych, United Kingdom). WC was measured at the level of the last rib while subjects were in a standing position. All anthropometric data were obtained by using the procedures described in the *Anthropometric Standardization Reference Manual* (17).

**Determination of BMI and WC classification**

The subjects were divided into 3 groups on the basis of their WC and into 3 groups on the basis of their BMI according to established classification standards (Figures 1 and 2). For WC,
we used the cutoffs that were proposed by Lean et al (18) and adopted by the World Health Organization (12): low risk (≤ 79 cm in women, ≤ 93 cm in men), increased risk (80–87 cm in women, 94–101 cm in men), and substantially increased risk (≥ 88 cm in women, >102 cm in men). For BMI, we used the cutoffs proposed by the National Institutes of Health (11) and the World Health Organization (12): normal weight (18.5–24.9), overweight (25.0–29.9), and class I obesity (30.0–34.9). Because all of the subjects who were underweight (BMI < 18.5) had WC values within the lowest WC category and all of those with class II and III obesity (BMI: ≥ 35.0) had WC values within the highest WC category, we did not examine the influence of BMI and WC in these subjects (Figures 1 and 2).

Statistical analysis

Sex differences in anthropometric and MRI variables were tested for significance by unpaired t tests (Table 1). Within each sex, Pearson’s product-moment correlation coefficients were used to investigate the linear relations among the different anthropometric and MRI variables (Table 2). The strength of the correlations between the anthropometric and MRI variables were compared by using the method of Hotelling (19). Multiple regression analyses were performed to determine whether the combination of BMI and WC explained a greater variance in total and regional fat by comparison with BMI alone (Table 2). Although WC and BMI were highly correlated (r = 0.92 and 0.79 in women and men, respectively), the colinearity diagnostics indicated that WC and BMI could be used in the same multiple regression model. To determine whether there were systematic differences between the 2 laboratories, the laboratory site was included in the multiple regressions as a covariate. Without exception, the inclusion of the laboratory site did not change the findings. Within each sex, total and regional fat were compared in combinations of different BMI and WC categories by using an analysis of variance (ANOVA) (Figures 1 and 2). An analysis of covariance (ANCOVA) was also performed to determine whether these comparisons differed after age was controlled for. When the ANOVA or ANCOVA P value was <0.05, a Tukey’s post hoc comparison test was used to locate specific group differences. Data are expressed as group means ± SDs. The two-tailed 0.05 level of significance was used for all data analysis. Data were analyzed by using SYSTAT software (version 5.0; SYSTAT Inc, Evanston, IL).

RESULTS

Subject characteristics

Both men and women varied widely in age and in total, nonabdominal, abdominal subcutaneous, and visceral fat (Table 1). With the exception of age, BMI, and abdominal subcutaneous fat, characteristics among the men and women were significantly different (P < 0.05). Compared with women, the men had a significantly greater ratio of visceral to total fat (11 ± 6% compared with 4 ± 2%; P < 0.001), a significantly greater ratio of visceral to abdominal subcutaneous fat (81 ± 65% compared with 37 ± 25%; P < 0.001), and a significantly lower ratio of nonabdominal to total fat (75 ± 6% compared with 83 ± 5%; P < 0.001).

Prediction of total, abdominal, nonabdominal, and abdominal subcutaneous fat by BMI and WC

Simple regression analysis

In the women, BMI and WC were significantly correlated (P < 0.001) with total, nonabdominal, and abdominal subcutaneous fat by a similar order of magnitude (Table 2). In the men, BMI was a stronger correlate (P < 0.05) of total, nonabdominal, and...
The primary observation of the present study is that independent of age, BMI and WC independently contribute to the prediction of nonabdominal, abdominal subcutaneous, and visceral fat in white men and women varying widely in age and adiposity. Inasmuch as excess nonabdominal, abdominal subcutaneous, or visceral fat predict the relative risk of disease, this observation underscores the importance of incorporating both anthropometric methods into routine clinical practice.

**DISCUSSION**

The results of the multiple regression analysis—performed to determine whether BMI and WC combined explained a greater variance in total, nonabdominal, abdominal subcutaneous, and visceral fat than did BMI or WC alone—are shown in Table 3. The addition of WC to BMI increased the variance explained in total and nonabdominal fat depots, ~20–40% of the variance in these variables remained unexplained by BMI or WC, thus confirming the limitation of using either value alone to estimate fat depots on an individual basis.

**Multiple regression analysis**

The comparisons of total and regional fat by categories of BMI and WC in women and men are shown in Figures 1 and 2, respectively. Independent of sex, an increase in the WC category was associated with corresponding significant increases in total fat and in the different fat depots within each of the 3 BMI categories. An exception to this finding was in overweight persons, in whom an increase in WC from the low risk to the increased risk category was not significantly associated with an increase in total or regional fat. Furthermore, the WC category was not significantly associated with increases in abdominal subcutaneous fat in overweight subjects and obese women. These observations did not change significantly after adjustment for age in the different BMI and WC categories (by ANCOVA).

**TABLE 1**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Women (n = 135)</th>
<th>Men (n = 206)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anthropometric</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (y)</td>
<td>44.0 ± 15.6 (18–88)</td>
<td>42.8 ± 13.4 (18–84)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>74.7 ± 18.7 (42.3–129.6)</td>
<td>90.8 ± 15.2 (54.7–137.2)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>27.8 ± 6.6 (15.9–47.8)</td>
<td>28.7 ± 4.6 (19.4–40.8)</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>85.6 ± 15.4 (63.0–135.0)</td>
<td>99.5 ± 13.3 (69.5–127.0)</td>
</tr>
<tr>
<td><strong>Fat mass</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (kg)</td>
<td>28.7 ± 13.8 (7.9–73.8)</td>
<td>24.5 ± 10.1 (6.1–53.7)</td>
</tr>
<tr>
<td>Abdominal (kg)</td>
<td>4.8 ± 2.7 (1.0–12.7)</td>
<td>6.3 ± 3.0 (0.9–13.6)</td>
</tr>
<tr>
<td>Nonabdominal (kg)</td>
<td>24.1 ± 11.7 (7.1–65.7)</td>
<td>18.3 ± 7.4 (5.2–40.4)</td>
</tr>
<tr>
<td>Abdominal subcutaneous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (kg)</td>
<td>3.5 ± 1.9 (0.9–10.9)</td>
<td>3.6 ± 1.8 (0.6–9.6)</td>
</tr>
<tr>
<td>L4–L5 area (cm²)</td>
<td>250 ± 145 (45–946)</td>
<td>238 ± 114 (36–607)</td>
</tr>
<tr>
<td>Visceral</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (kg)</td>
<td>1.3 ± 1.0 (0.1–5.1)</td>
<td>2.7 ± 1.7 (0.1–9.5)</td>
</tr>
<tr>
<td>L4–L5 area (cm²)</td>
<td>77 ± 59 (3–290)</td>
<td>137 ± 83 (3–482)</td>
</tr>
</tbody>
</table>

1 ± SD; range in parentheses.

2 Significantly different from women, *P < 0.05* (unpaired *t* test).

3 Measured by magnetic resonance imaging.

**TABLE 2**

<table>
<thead>
<tr>
<th>Fat mass</th>
<th>Women (n = 135)</th>
<th>Men (n = 206)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.92</td>
<td>0.78&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>BMI</td>
<td>0.87</td>
<td>0.68</td>
</tr>
<tr>
<td>Waist circumference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abdominal</td>
<td>0.68</td>
<td>0.76&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>BMI</td>
<td>0.73</td>
<td>0.68</td>
</tr>
<tr>
<td>Waist circumference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonabdominal</td>
<td>0.89</td>
<td>0.73&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>BMI</td>
<td>0.83</td>
<td>0.62</td>
</tr>
<tr>
<td>Waist circumference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abdominal subcutaneous</td>
<td>0.53</td>
<td>0.72&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>BMI</td>
<td>0.52</td>
<td>0.49</td>
</tr>
<tr>
<td>Waist circumference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visceral</td>
<td>0.60&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.46&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>BMI</td>
<td>0.76</td>
<td>0.55</td>
</tr>
</tbody>
</table>

<sup>1</sup> All correlations were significant, *P < 0.001* (Pearson’s product-moment correlation coefficients).

<sup>2</sup> Significantly different from waist circumference, *P < 0.05*. 

abdominal subcutaneous fat mass than was WC. Independent of sex, WC was a stronger correlate of visceral fat than was BMI (*P < 0.001*). Although both BMI and WC were strong correlates of nonabdominal and abdominal fat depots, ~20–40% of the variance in these variables remained unexplained by BMI or WC, thus confirming the limitation of using either value alone to estimate these fat depots on an individual basis.

**Multiple regression analysis**

The comparisons of total and regional fat by categories of BMI and WC in women and men are shown in Figures 1 and 2, respectively. Independent of sex, an increase in the WC category was associated with corresponding significant increases in total fat and in the different fat depots within each of the 3 BMI categories. An exception to this finding was in overweight persons, in whom an increase in WC from the low risk to the increased risk category was not significantly associated with an increase in total or regional fat. Furthermore, the WC category was not significantly associated with increases in abdominal subcutaneous fat in overweight subjects and obese women. These observations did not change significantly after adjustment for age in the different BMI and WC categories (by ANCOVA).
It is now well established that WC remains a significant predictor of type 2 diabetes and cardiovascular disease after control for BMI in both men and women (3–7). It is often suggested that the ability of WC to predict health risk beyond that predicted by BMI alone is explained by the ability of WC to act as a surrogate for abdominal fat (11, 12). Consistent with previous observations (20, 21), our findings indicate that BMI and WC are related to abdominal fat by a similar order of magnitude independent of age and sex. However, our results indicate that the use of WC in combination with BMI is a better predictor of abdominal fat than is BMI alone, explaining an additional 6% of the variation in abdominal obesity. More importantly, our findings show that the variation in abdominal fat explained by WC is explained almost exclusively by the ability of WC measurements to predict visceral fat. Indeed, whereas the addition of WC to BMI explained an additional 11% and 16% of the variation in visceral fat in the men and women, respectively, the measurement of WC was not a clinically significant predictor of abdominal subcutaneous fat after BMI was controlled for. Moreover, the fact that WC was only a modest predictor of nonabdominal fat after controlling for BMI (<3%) suggests that nonabdominal and abdominal subcutaneous fat are not vehicles by which WC explains health risk beyond that predicted by BMI.

To further investigate the ability of WC to independently predict total and regional fat mass, we divided the cohort into the subcategories (Figures 1 and 2) currently used to identify disease risk by BMI and WC (11). Again, if one assumes that the independent health risk predicted by WC is related to its ability to act as a surrogate for abdominal fat, we reasoned that within each BMI category (normal weight, overweight, and class I obese), levels of abdominal fat would increase with incremental increases in the WC category. Indeed, within each BMI category, those in the high WC category had substantially greater quantities of abdominal fat by comparison to those in the low WC category. With few exceptions, the increase in abdominal fat with increasing WC category was almost entirely accounted for by visceral fat, which agrees with our finding that compared with BMI alone, WC independently predicts visceral but not abdominal subcutaneous fat. For example, in overweight men and women, visceral fat accounted for >83% of the increase in abdominal fat observed across the 3 WC categories. These observations support the validity of the current classification guidelines (11, 12) that incorporate BMI and WC to identify those at increased health risk and suggest that the ability of WC to predict health risk beyond that predicted by BMI may be explained by the ability of WC to identify those individuals with elevations in visceral fat.

Although it is established that WC remains a significant predictor of type 2 diabetes and cardiovascular disease after BMI is controlled for (3–7), we are unaware of studies showing that BMI predicts health risk independent of WC. However, the findings of the present study suggest that the combined use of BMI and WC values substantially increased the variance explained in abdominal subcutaneous fat. Because it was reported that abdominal subcutaneous fat is an independent predictor of insulin resistance (22, 23), our findings provide further support for the notion that BMI and WC combined better predict metabolic risk than does either variable alone. Thus, the health risks associated with abdominal obesity are best identified by the combination of BMI and WC, not WC alone.

In summary, we have shown that BMI and WC independently contribute to the prediction of total, nonabdominal, abdominal subcutaneous, and visceral fat within a large cohort of white men and women varying widely in age and adiposity. This observation underscores the recommendation that health care practitioners routinely use both anthropometric variables to identify those at increased health risk as a result of excess total, abdominal, and visceral fat.

### REFERENCES