Patterns of Abdominal Fat Distribution

Pou, Karla M.

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Boston University
Patterns of Abdominal Fat Distribution

The Framingham Heart Study

Karla M. Pou, MD1
Joseph M. Massaro, PhD2
Udo Hoffmann, MD, MPH3
Kathrin Lieb, MD4
Ramachandran S. Vasan, MD4
Christopher J. O’Donnell, MD, MPH4,5
Caroline S. Fox, MD, MPH1,4

OBJECTIVE — The prevalence of abdominal obesity exceeds that of general obesity. We sought to determine the prevalence of abdominal subcutaneous and visceral obesity and to characterize the different patterns of fat distribution in a community-based sample.

RESEARCH DESIGN AND METHODS — Participants from the Framingham Heart Study (n = 3,348, 48% women, mean age 52 years) underwent multidetector computed tomography, subcutaneous adipose tissue (SAT) and visceral adipose tissue (VAT) volumes were assessed. Sex-specific high SAT and VAT definitions were based on 90th percentile cut points from a healthy referent sample. Metabolic risk factors were examined in subgroups with elevated SAT and VAT.

RESULTS — The prevalence of high SAT was 30% (women) and 31% (men) and that for high VAT was 44% (women) and 42% (men). Overall, 27.8% of the sample was discordant for high SAT and high VAT: 19.9% had SAT less than but VAT equal to or greater than the 90th percentile, and 7.9% had SAT greater than but VAT less than the 90th percentile. The prevalence of metabolic syndrome was higher among men and women with SAT less than the 90th percentile and high VAT than in those with high SAT but VAT less than the 90th percentile, despite lower BMI and waist circumference. Findings were similar for hypertension, elevated triglycerides, and low HDL cholesterol.

CONCLUSIONS — Nearly one-third of our sample has abdominal subcutaneous obesity, and >40% have visceral obesity. Clinical measures of BMI and waist circumference may misclassify individuals in terms of VAT and metabolic risk.

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Obesity is associated with an increased risk of multiple cardiometabolic risk factors. The prevalence of obesity in the U.S. has increased over the last two decades, with one-third of adults having a BMI ≥30 kg/m² (1). However, obesity is a heterogeneous condition with individual differences in the pattern of adipose tissue deposition. Accumulation of abdominal fat, particularly in the visceral compartment, may confer the majority of obesity-associated health risks (2).

The prevalence of abdominal obesity (defined as waist circumference ≥88 cm in women and ≥102 cm in men) has increased over the last decade and now exceeds the prevalence of overall obesity, with rates of 42.4% in men and 61.3% in women (1,3). Notably, the largest relative increase in the prevalence of abdominal obesity has been among individuals with BMI <30 kg/m² (3). Although waist circumference is an easily obtainable index of abdominal adiposity, it does not distinguish between the subcutaneous and visceral adipose tissue compartments. We and others have previously reported that visceral adipose tissue (VAT) has a stronger association with metabolic risk factors and metabolic syndrome than subcutaneous adipose tissue (SAT) (4–6). These studies are limited, however, by the high correlations between SAT and VAT that make it difficult to distinguish between the contribution of SAT compared with that of VAT with regard to metabolic risk.

Thus, the objectives of the present study were twofold. First, we sought to define the prevalence of abdominal obesity in terms of elevated volumes of VAT and SAT, as measured by a volumetric computed tomography (CT) method. To do this, we developed cut points for elevated SAT and VAT based on a healthy referent sample. Second, we examined the occurrence of different patterns of adipose tissue distribution and concomitant metabolic risk factor profiles. We hypothesized that metabolic risk factors would be more likely to track with elevated levels of VAT than with SAT.

RESEARCH DESIGN AND METHODS — The study sample consisted of women and men enrolled in the community-based Framingham Heart Study Offspring and Third Generation cohorts who participated in a multidetector computed tomography (MDCT) substudy. As part of the MDCT substudy, 3,529 participants (2,111 Third Generation and 1,418 Offspring participants) underwent MDCT scanning of the chest and abdomen for assessment of coronary and aortic calcium between June 2002 and April 2005. Of the total 3,529 subjects imaged, 3,371 had interpretable CT measures and 3,348 had both SAT and VAT measured, resulting in a total sample size of 3,348 individuals for the present investigation.

The study protocol was approved by the institutional review boards of the Boston University Medical Center and Massachusetts General Hospital. All subjects provided written informed consent.
Additional details regarding the study sample selection, abdominal adipose tissue imaging and volumetric measurements, risk factor assessment, and statistical analysis can be found in the supplemental methods (available in an online appendix at http://dx.doi.org/10.2337/dc08-1359).

RESULTS

Overall, 1,611 women and 1,737 men were available for analysis; study sample characteristics are shown in Table 1. SAT and VAT percentiles in women and men by age are shown in supplemental Table A1.

Healthy referent group

The healthy referent sample was composed of 471 women and 285 men. The 90th percentile cutoffs of SAT and VAT for this healthy referent group were 3,735 and 1,359 cm$^3$, respectively, in women and 2,979 and 2,323 cm$^3$ in men.

Prevalence of elevated SAT and VAT by BMI and waist circumference categories

The prevalence of subcutaneous abdominal obesity (high SAT) in the overall sample was 30% in women and 31% in men. The prevalence of visceral obesity (high VAT) was 44% in women and 42% in men. The prevalence of high SAT and high VAT by age-group is presented in Fig. 1.

In a secondary analysis, the lean healthy referent (further excluding individuals with BMI $\geq$25 kg/m$^2$) 90th percentile cut points in this sample were 2,883 and 2,031 cm$^3$ for SAT and 1,062 and 1,715 cm$^3$ for VAT in women and men, respectively. Applying these cut points to the overall sample would result in the prevalence of high SAT of 50% in women and 66% in men and high VAT of 56% in women and 67% in men.

Prevalence of high SAT and high VAT among SAT and VAT subgroups

The prevalence of metabolic syndrome was significantly different across the four SAT/VAT groups ($P = 0.0001$ across the four groups) (Fig. 3); clinical characteristics of these groups are shown in Table 2.

Overall, 49.3% of the sample had both SAT and VAT $\geq$90th percentile, whereas 22.9% had both high SAT and VAT. Nearly 28% of the sample was discordant in terms of SAT and VAT: 7.9% had high SAT and VAT $\geq$90th percentile, whereas 19.9% had SAT $\geq$90th percentile but high VAT. The mean age was higher among those with SAT $\geq$90th percentile and high VAT compared with those with high SAT and VAT $\geq$90th percentile. The prevalence of metabolic syndrome was higher among those with SAT $\geq$90th percentile and high VAT compared with those with high SAT and VAT $\geq$90th percentile. The prevalence of metabolic syndrome was higher among those with high SAT and high VAT compared with the group with high SAT and VAT $\geq$90th percentile (Fig. 3); similar patterns were noted for elevated triglycerides and low HDL cholesterol. This pattern was not explained by a higher body weight or ab-

Table 1—Clinical characteristics of overall sample

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>1,611</td>
<td>1,737</td>
</tr>
<tr>
<td>Age (years)</td>
<td>52.2 ± 9.9</td>
<td>49.8 ± 10.7</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>27.1 ± 5.8</td>
<td>28.4 ± 4.5</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>93 ± 15</td>
<td>101 ± 12</td>
</tr>
<tr>
<td>Low HDL cholesterol (%)*</td>
<td>26</td>
<td>33</td>
</tr>
<tr>
<td>Elevated triglycerides (%)†</td>
<td>27</td>
<td>44</td>
</tr>
<tr>
<td>Hypertension (%)</td>
<td>26.8</td>
<td>32.0</td>
</tr>
<tr>
<td>Impaired fasting glucose (%)‡</td>
<td>19</td>
<td>40</td>
</tr>
<tr>
<td>Diabetes (%)</td>
<td>5.6</td>
<td>7.4</td>
</tr>
<tr>
<td>Metabolic syndrome (%)</td>
<td>28</td>
<td>38</td>
</tr>
<tr>
<td>CVD (%)</td>
<td>4.3</td>
<td>7.8</td>
</tr>
<tr>
<td>Hypertension treatment (%)</td>
<td>18.7</td>
<td>19.8</td>
</tr>
<tr>
<td>Lipid treatment (%)</td>
<td>10.7</td>
<td>17.7</td>
</tr>
<tr>
<td>Diabetes treatment (%)</td>
<td>3.3</td>
<td>3.9</td>
</tr>
<tr>
<td>SAT (cm$^3$)</td>
<td>3,148 ± 1,519</td>
<td>2,640 ± 1,206</td>
</tr>
<tr>
<td>VAT (cm$^3$)</td>
<td>1,365 ± 832</td>
<td>2,243 ± 1,023</td>
</tr>
</tbody>
</table>

Data are means ± SD or %. *Low HDL defined as <40 mg/dl (men) and <50 (women). †Elevated triglycerides defined as ≥150 mg/dl or lipid treatment. ‡Defined as fasting plasma glucose 100–125 mg/dl in the absence of diabetes treatment.
30% of our sample, and adverse meta-
amounts of SAT and VAT exist in nearly
useful adiposity categories. Discordant
misclassification exists within clinically
difference have high VAT, suggesting that
20% of men with a normal waist circum-
ervated VAT, whereas 10% of women and
one-quarter of obese individuals or indi-
clines among elderly individuals. Nearly
rises with age, whereas elevated VAT de-
percentile cut points in a healthy referent
volumetric measures of both SAT and
major findings
Volumetric measures of both SAT and
VAT revealed a prevalence of high SAT of
∼30% and a prevalence of high VAT of
just more than 40% as defined by 90th
percentile cut points in a healthy referent
sample. The prevalence of elevated VAT
rises with age, whereas elevated SAT de-
clines among elderly individuals. Nearly
one-quarter of obese individuals or indi-
viduals with a large waist do not have el-
evated VAT, whereas 10% of women and
20% of men with a normal waist circum-
ference have high VAT, suggesting that
misclassification exists within clinically
useful adiposity categories. Discordant
amounts of SAT and VAT exist in nearly
30% of our sample, and adverse metab-
olic risk factor profiles are more likely to
track with those with elevated VAT com-
pared with elevated SAT. Last, among
these discordant obesity subgroups, BMI
and waist circumference were actually
lower among higher risk groups.

We secondarily evaluated a “lean
healthy referent” sample and found that
the prevalence of elevated VAT and SAT
was even higher than that for the sample
that included overweight individuals in
the healthy referent sample. Given that
the lean healthy referent sample excluded
overweight individuals, this result is not
surprising. However, the lean healthy re-
ferent sample consisted of <500 individ-
uals, and the robustness of these estimates
is not clear.

The prevalence of elevated SAT de-
clines with age, whereas elevated VAT
rises among older individuals. These find-
ings are consistent with the observation
that the aging process is associated with
loss of subcutaneous fat and gain of fat
accumulation in the visceral depot. De-
spite more visceral fat but less subcutane-
ous fat among older individuals, BMI
actually declines with age (7) primarily
because of loss of fat-free mass and fat
mass. Both BMI and waist circumference
are more strongly correlated with subcu-
taneous than with visceral fat (4). There-
fore, both anthropometric measures may
be less reliable in aging individuals, as
BMI and waist circumference may be
more dependent on the relative loss of
SAT over time. This is consistent with the
observation in the present article that al-
though individuals with high VAT and
SAT <90th percentile had more adverse
risk factor profiles, BMI and waist circum-
ference were actually lower compared
with those in individuals with high SAT
and VAT <90th percentile.

In the context of the current
literature
In our cohort, the prevalence of subcuta-
neous adiposity is ∼30%, which is con-
sistent with current estimates of the
prevalence of obesity (as defined by a BMI
of at least 30 kg/m²) of 32.2% in U.S.
adults (1). The prevalence of visceral obe-
ity in our sample (42% in men and 44%
in women) exceeds the prevalence of sub-
cutaneous adiposity. Of note, the preva-
ience of abdominal obesity in women
(defined by a waist circumference >88
cm) in National Health and Nutrition Ex-
amination Survey data is higher than the
prevalence of visceral obesity (defined by
VAT ≥90th percentile healthy referent
cut point) in our sample of women (61.3
vs. 44%). This difference was not ob-
served in men. However, clinical anthro-
pometrics are well-known to be poor for
estimating VAT, and, thus, it is not sur-
prising that there is a discrepancy be-
tween a prevalence based on waist
circumference and one based on more
precise CT measurements (8).

Clinical categories to classify BMI and
waist circumference are useful for pre-
dicting risk of adiposity-related disorders
in the majority of patients, but misclassi-
ification exists (9). Some individuals who
have normal BMI and normal waist cir-
 circumference have an excessive amount
of visceral fat that is unrecognized and thus
have a significant cardiometabolic risk.
This phenotype of a metabolically obese
normal-weight individual was first de-
scribed in the 1980s by Ruderman et al.
(10) and was classified as an individual
with a nonobese BMI who showed evi-
dence of impaired insulin sensitivity with
a hyperinsulinemic-euglycemic clamp.
 Conversely, the metabolically healthy
obese individual (11) represents individ-
uals with a high BMI who seem to be
protected from associated metabolic de-

Figure 2—Prevalence of high SAT or high VAT by BMI category in women (A) and men (B) and
by waist circumference category in women (C) and men (D). Error bars represent SE. A and B: ■,
normal weight; ■, overweight; ■, obese. C and D: ■, normal waist circumference; □, high waist
circumference.
Patterns of abdominal fat distribution

To further explore the existence of different fat phenotypes in a community-based setting, we looked at groups that were discordant for SAT and VAT and found that the group with low SAT but high VAT had a greater prevalence of metabolic syndrome than the group with high SAT but low VAT. The collinearity of SAT and VAT (correlations ranging between 0.58 in men and 0.71 in women) (4) makes it difficult to assess the differential contribution of SAT compared with VAT with regard to metabolic risk. However, the examination of risk factors among discordant categories of high SAT and high VAT in our study suggests that a more adverse risk factor profile tracks with high VAT than with high SAT. This suggestion is supported by the extensive literature suggesting a uniquely important contribution of visceral fat to metabolic risk and a correlation of excess VAT with metabolic risk independent of SAT (12–16). Nonetheless, it is important to note that the mean BMI and waist circumference were actually lower among participants with elevated VAT and normal SAT, highlighting the potential misclassification in clinical anthropometrics.

Compared with the high SAT and high VAT group, the low SAT and high VAT group had a higher prevalence of hypertriglyceridemia. These findings may be consistent with a pattern similar to the metabolic abnormalities present in partial lipodystrophy. The lack of sufficient adipocytes and the limited capacity to store fat in nonlipodystrophic adipose tissue may result in ectopic fat storage around other tissues and organs such as the heart, the liver, skeletal muscles, blood vessels, and kidneys (17,18). This ectopic fat storage may lead to organ dysfunction (19).

Figure 3—Prevalence of metabolic risk factors (MetS) and CVD by SAT/VAT concordant and discordant categories in women (A) and men (B). Age-adjusted \( P < 0.0001 \) across all four categories for each risk factor except cardiovascular disease \( (P = 0.01 \) for men and \( P = 0.05 \) for women). \( \ast P < 0.01 \) for the low SAT/high VAT and high SAT/low VAT comparisons. Error bars represent upper one-sided 97.5% CIs. HTN, hypertension; IFG, impaired fasting glucose; TG, triglyceride; \( \square \), low SAT and VAT; \( \square \), high SAT and low VAT; \( \blacklozenge \), low SAT and high VAT; \( \blacksquare \), high SAT and VAT.

Table 2—Distribution of risk factors and clinical characteristics by SAT/VAT categories*

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Low SAT/low VAT</th>
<th>High SAT/low VAT</th>
<th>Low SAT/high VAT</th>
<th>High SAT/high VAT</th>
<th>( P ) value comparing discordant SAT and VAT</th>
<th>( P ) value across groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n )</td>
<td>1,650</td>
<td>266</td>
<td>666</td>
<td>766</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Men</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>49</td>
<td>47</td>
<td>58</td>
<td>54</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.6</td>
<td>30.2</td>
<td>28.5</td>
<td>34.0</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>93</td>
<td>107</td>
<td>101</td>
<td>116</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SAT (cm³)</td>
<td>1,861</td>
<td>3,753</td>
<td>2,317</td>
<td>4,190</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>VAT (cm³)</td>
<td>1,532</td>
<td>1,898</td>
<td>2,959</td>
<td>3,315</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>51</td>
<td>51</td>
<td>61</td>
<td>56</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.2</td>
<td>29.5</td>
<td>27.1</td>
<td>34.4</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>83</td>
<td>99</td>
<td>95</td>
<td>112</td>
<td>0.0002</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SAT (cm³)</td>
<td>2,088</td>
<td>4,330</td>
<td>2,955</td>
<td>5,157</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>VAT (cm³)</td>
<td>773</td>
<td>1,103</td>
<td>1,831</td>
<td>2,283</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

SAT and VAT categories are defined as high if \( \geq 90 \text{th percentile cut points in healthy referent sample: SAT, men} = 2,979 \text{ cm}^3; \text{ women} = 3,735 \text{ cm}^3; \text{ VAT, men} = 2,323 \text{ cm}^3; \text{ women} = 1,359 \text{ cm}^3. \)
Implications: limitations of BMI and waist circumference, particularly among older individuals

Clinical categories of BMI and waist circumference may be useful to estimate overall metabolic risk in the general population, but there may be individuals who develop cardiometabolic complications related to adiposity without a BMI or waist circumference in the high-risk range. In particular, we observed that among individuals discordant for high SAT and VAT, BMI and waist circumference were actually lower among those with high VAT and low SAT, despite having a higher prevalence of metabolic risk factors. Therefore, the reliance on BMI and waist circumference in the aging population may misclassify metabolic risk.

Strengths and limitations

Strengths of our study include the use of a large community-based sample with detailed risk factor assessment. We used a highly reproducible CT assessment of SAT and VAT volumes, which accounts for heterogeneity of fat distribution throughout the abdomen. Our sample size was large enough to explore differences within obesity subgroups. Our study is a population-based epidemiologic study without ascertainment for obesity-related conditions, which increases the generalizability of our findings. Limitations include the use of cross-sectional data, as causality cannot be inferred. Because the Framingham Offspring study is primarily a Caucasian sample, generalizability to other races or ethnic groups is uncertain.

In summary, nearly one-third of our sample has abdominal subcutaneous obesity and more than 40% have visceral obesity. Different patterns of adipose tissue distribution have different metabolic correlates. Clinical measures of BMI and waist circumference may misclassify individuals in terms of metabolic risk.

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No potential conflicts of interest relevant to this article were reported.

References