Sex-specific Associations of Magnetic Resonance Imaging-derived Intra-abdominal and Subcutaneous Fat Areas with Conventional Anthropometric Indices

The Atherosclerosis Risk in Communities Study

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Accurate measurement of central fat patterning is difficult to obtain by conventional anthropometry. Direct measurement of intra-abdominal fat area by magnetic resonance imaging, while accurate, is impractical for large-scale observational studies. This report examines the sex-specific associations of conventional anthropometric indices with intra-abdominal fat and subcutaneous fat areas measured by magnetic resonance imaging. A total of 157 volunteers (97 men and 60 women) aged 48–68 years of predominately white ethnicity had intra-abdominal fat and subcutaneous fat areas measured as part of the Atherosclerosis Risk in Communities (ARIC) Study. Weight, body mass index, waist circumference, waist:hip ratio, and subscapular skinfold thickness were measured or calculated by a standardized protocol. On average, women had a lower intra-abdominal fat area than men (109.5 cm² vs. 152.9 cm²) but a higher mean subcutaneous fat area (287.8 cm² vs. 214.6 cm²). After adjustment for age, intra-abdominal fat area was quadratically associated with body mass index, waist circumference, and subscapular skinfold thickness in men; in women, these associations were best modeled by a positive linear equation. Waist:hip ratio was linearly related to intra-abdominal fat area in both sexes. In general, anthropometric measures predicted lower percentages of the total variance in intra-abdominal fat area for men than for women. For subcutaneous fat area, all anthropometric indices were linearly associated and predicted more of the variance in subcutaneous fat area than in intra-abdominal fat area. These results indicate that among men, greater intra-abdominal fat deposition rates occur at relatively low body weights and fat is more uniformly deposited at higher weights. Women appear to deposit intra-abdominal fat at a constant rate as they gain weight, even after menopause. The authors conclude that when waist circumference or body mass index is used as a surrogate for intra-abdominal fat area in men, a quadratic term should be included in the analysis as a predictor variable. Subcutaneous fat area can be estimated well by linear measures commonly employed in epidemiologic studies. Am J Epidemiol 1996; 144:335–45.
abdominal fat on cardiovascular outcomes (9). Waist circumference can also become more difficult to assess in an aging population because of gravitational effects on the most commonly used landmark for this measure, the umbilicus. Further complicating the age association, fat deposition patterns prior to menopause tend to vary by sex as well (10).

If intra-abdominal fat is the component of android fat patterning that is linked to metabolic aberrations such as hyperinsulinemia, a direct measure of visceral fat area would be expected to improve the accuracy of associations with cardiovascular risk factors or events. Computed tomographic scanning can directly visualize the intra-abdominal region, but it involves the use of ionizing radiation and thus may not be feasible for all populations or for repeatability studies (11, 12). Recently, magnetic resonance imaging has been shown to produce images of the intra-abdominal region that are comparable to those obtained by computed tomography, with high measurement reliability (13-17).

Therefore, the following research questions were investigated in this report. First, do intra-abdominal and subcutaneous fat areas at the umbilicus, measured by magnetic resonance imaging, vary between the sexes in a group of volunteers falling within a relatively narrow age range? Second, given that magnetic resonance imaging is less suitable for large-scale observational studies in free-living populations than conventional anthropometric indices, how do these fat area measurements compare with the adiposity measures of body mass index, body weight, waist circumference, waist:hip ratio, and subscapular skinfold thickness, and do these comparisons vary between men and women?

MATERIALS AND METHODS

Participants were recruited from the Forsyth County, North Carolina, field center of the Atherosclerosis Risk in Communities (ARIC) Study during the first follow-up visit in 1990–1992. The design and objectives of the ARIC Study have been presented elsewhere (18). Briefly, the ARIC Study is a prospective, multicenter investigation of the etiology and natural history of noninvasively measured atherosclerosis and its clinical sequelae. Three of the four field centers—Forsyth County, North Carolina; Minneapolis, Minnesota; and Washington County, Maryland—examined a general population sample from the appropriate age range (45–64 years at the baseline examination (1987–1989)); the fourth center, Jackson, Mississippi, derived its population entirely from the African-American residents of Jackson. The source population used in the current investigation was systematically derived from the entire ARIC Study cohort as a group of participants who were free of prevalent cardiovascular and cerebrovascular disease at entrance into the study, with approximately 50 percent having carotid atherosclerosis as assessed by B-mode ultrasonography and the other 50 percent matched to the first group by race, sex, age, and date of examination but having no evidence of preclinical carotid atherosclerosis. The selection of the subsample has been described in detail elsewhere (19).

A total of 157 participants (60 women and 97 men) aged 47–68 years from the source population described above volunteered to have magnetic resonance images of their abdomens made at the level of the second and the fourth lumbar vertebrae between November 1991 and March 1993. Exclusion criteria for magnetic resonance imaging included claustrophobia and the presence of any metal objects in the body such as surgical clips, fragments, prosthetic devices, or pacemakers.

The magnetic resonance images were obtained by the inversion recovery method, described by Terry et al. (20) and previously validated against computed tomographic scanning. In brief, the participant was asked to lie in a supine position. Magnetic resonance imaging was performed on a Picker Vista 2055 HP MR scanner (Picker Vista, Cleveland, Ohio) operating at a field of 1.5 T (17), based on a modification of the method of Seidell et al. (21). Imaging parameters were as follows: inversion time = 300 msec, repetition time = 833 msec, and echo time = 30 msec. Four slices of 10-mm thickness were obtained with 5 mm between slices, with the field image dependent on the size of each participant. The images generated from these slices were stored on magnetic tape and transferred to a work station with software dedicated for measurement of fat area. The third slice was centered at the umbilicus, comparable to the third lumbar vertebra, and was used as the reference point in these fat area estimations.

Fat area was estimated by the pixel density technique. This technique involves standardizing the signal intensity of fat on a representative region of subcutaneous fat and then circumscribing the entire computer image with a mouse to obtain total fat area (17). Intra-abdominal fat area and spinal fat area were obtained in an analogous fashion. Subcutaneous fat area was derived as the remaining component of total fat area after intra-abdominal and spinal fat area had been removed. Because previous data suggested that the areas estimated by this technique were highly correlated between slices (J. G. T., unpublished observations), the slice centered at the umbilicus was used for all of the data described here. Values for intra-
abdominal and subcutaneous fat areas used in the analyses were expressed as the means of two readings taken at the umbilicus.

Conventional anthropometric indices were those obtained and standardized for the entire ARIC Study cohort. Weight and standing height were measured without shoes with the participant standing erect and looking straight ahead. Weight was measured to the nearest pound (rounding down) and height was measured to the nearest centimeter (also rounding down). Waist circumference was measured with the tape measure placed horizontally at the level of the umbilicus while the participant breathed quietly; hip circumference was measured at the maximal protrusion of the gluteal muscles, as verified by passing the tape measure above and below the observed maximum. For both waist and hip circumferences, readings were made to the nearest centimeter (rounding down). Body mass index was calculated as weight in kilograms divided by height in meters squared. Frame size was approximated by elbow breadth, measured with the participant’s right arm raised to the horizontal position, and a sliding caliper was used to measure the distance between the lateral and medial epicondyles in millimeters (rounding down). Complete information on anthropometric measurements, training, and certification can be found in ARIC Manual of Operations number 2 (22).

Statistical analyses were performed using version 6.08 of the Statistical Analysis System (SAS), including means, frequencies, and Pearson correlation coefficients (23). Differences between the sexes for the mean values of continuous variables were assessed by t test; for categorical variables, the Pearson $\chi^2$ statistic was used. Residual scatterplots were constructed to assess homoscedasticity for sex-specific linear models; no evidence of heteroscedasticity was apparent. Sex-specific multivariable linear regression was conducted to obtain parameter estimates for independent predictor variables, and testing of statistical interactions was accomplished by general linear techniques in models containing sex and sex $\times$ anthropometric predictor interaction terms (24). Improvement of model fit by addition of a quadratic term was determined by the statistical significance of the quadratic parameter estimate and by a marked increase in the model’s $R^2$ value.

RESULTS

Mean values and frequencies for selected attributes of the subsample are presented in table 1. Men and women were of comparable ages (approximately 60 years) and had similar values for body mass index and subscapular skinfold thickness. The subsample was predominately white (93.3 percent and 95.9 percent of women and men, respectively), and men and women exhibited little difference in the prevalence of current

<table>
<thead>
<tr>
<th>TABLE 1. Mean values and frequencies of selected population attributes, by sex: Atherosclerosis Risk in Communities Study, 1990–1992</th>
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<tr>
<td></td>
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<tr>
<td>---------------------------------------------------------------</td>
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<tr>
<td>Age (years)</td>
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<tr>
<td>Height (cm)</td>
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<tr>
<td>Weight (pounds)‡</td>
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<tr>
<td>Body mass index§</td>
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<td>Waist circumference (cm)</td>
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<tr>
<td>Hip circumference (cm)</td>
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<tr>
<td>Waist:hip ratio</td>
</tr>
<tr>
<td>Subscapular skinfold thickness (mm)</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td>Current cigarette smoker</td>
</tr>
<tr>
<td>White race</td>
</tr>
<tr>
<td>Postmenopausal</td>
</tr>
</tbody>
</table>

* Calculated by t test for differences between means and by Pearson’s $\chi^2$ for differences between frequencies.
† SD, standard deviation.
‡ 1 pound = 0.45 kg.
§ Weight (kg)/height (m)².
cigarette smoking ($p$ for difference = 0.57). In addition, the majority of women in this subsample (92.7 percent) reported having already passed through menopause when asked if they had had a menstrual period during the past 2 years. On average, men were taller and heavier than women and had statistically significantly larger waist circumferences and waist:hip ratios.

Sex-specific distributional statistics for intra-abdominal fat and subcutaneous fat areas are presented in table 2. Mean intra-abdominal fat area values were higher in men than in women; intra-abdominal fat area was also higher at each percentile cutpoint (consistent with the relatively normal distribution of this variable). This sex difference in intra-abdominal fat area distribution was highly statistically significant by the two-independent-sample $t$ test. For subcutaneous fat area, the opposite situation existed: Women had significantly more subcutaneous fat at the abdomen than did men at all points of the distribution. In both men and women, mean subcutaneous fat area was greater than intra-abdominal fat area at all percentile cutpoints. The association between intra-abdominal fat and subcutaneous fat areas also varied by sex, with Pearson (linear) correlations equal to 0.502 and 0.186 in women and men, respectively.

Plots for intra-abdominal fat area versus weight, body mass index, waist circumference, waist:hip ratio, and subcapsular skinfold thickness are displayed in the top portion of figure 1; plots examining subcutaneous fat area versus the same anthropometric indices are presented in the lower portion. All of the anthropometric measures in figure 1 were statistically significantly correlated with intra-abdominal fat area and subcutaneous fat area, although the linear correlations between intra-abdominal fat area and standard anthropometric measures were markedly lower in men than in women (data not shown). For women, intra-abdominal fat area increased linearly with weight, while for men, the intra-abdominal fat deposition rate appeared to be greatest at relatively low weights. Subcutaneous fat area, however, appeared qualitatively to increase in a linear fashion with increasing weight for both sexes. Similarly, body mass index exhibited the same graphic trend as weight for both intra-abdominal fat area and subcutaneous fat area. Intra-abdominal fat area showed the same sex patterns with increasing waist circumference as did weight, although in men the increase in intra-abdominal fat area at smaller waist circumferences and subsequent plateauing was more pronounced for waist circumference than for weight. Subcutaneous fat area increased at comparable rates in both sexes as waist circumference increased. Waist:hip ratio differed from the previous anthropometric measures in that its association with intra-abdominal fat area in both sexes was linear, with intra-abdominal fat area increasing at a greater rate in men than in women. However, the univariate association of waist:hip ratio with subcutaneous fat area paralleled the associations observed with the above measures. Finally, subscapular skinfold thickness was qualitatively similar to weight, body mass index, and waist circumference in its sex-related associations with both intra-abdominal and subcutaneous fat areas.

While the plots in figure 1 give pictorial representations of the univariate associations of intra-abdominal fat and subcutaneous fat with conventional anthropometric measures, sex-specific, quantitative parameter estimates for independent predictors of intra-abdominal fat and subcutaneous fat areas are presented in tables 3 and 4, respectively. Although age was not correlated with intra-abdominal fat area for females in this subsample ($r = 0.041$), a positive correlation existed for males ($r = 0.242$). Therefore, these estimates were adjusted for age. Furthermore, the participants originally selected on the basis of preclinical asymptomatic atherosclerosis by B-mode ultrasound had higher values for intra-abdominal fat area than their comparison group (153.4 cm$^2$ vs. 122.9 cm$^2$, respectively; $p$ for difference = 0.0021). Therefore, the models were also adjusted for atherosclerotic status. In addition, atherosclerotic status was tested as an effect modifier for the association of intra-abdominal fat area with each anthropometric predictor and was found to be nonsignificant in all models (data not shown). Atherosclerotic status was neither a confounding factor nor an effect modifier for the association of subcutaneous fat area with the anthropometric predictors, but was included in these models for comparability with the intra-abdominal fat analyses.

In table 3, body mass index was linearly associated with intra-abdominal fat area in women, but in men, a

FIGURE 1. Sex-specific unadjusted scatterplots of intra-abdominal and subcutaneous fat areas according to weight, body mass index, waist circumference, waist: hip ratio, and subscapular skinfold thickness: Atherosclerosis Risk in Communities Study, 1990-1992. Quadratic or linear regression curves are plotted through the data (—, males; —, females).
A quadratic model provided a better fit for the data. These conclusions were based on both the highly statistically significant quadratic parameter estimate and the marked increase in the \( R^2 \) values between the linear and quadratic models in men (explaining 19.8 percent and 32.2 percent of the total model variance, respectively). In women, however, the quadratic term was not statistically significant and the \( R^2 \) values were similar for the two models; in addition, the sex \( \times \) body mass index and sex \( \times \) body mass index\(^2 \) interaction terms were not statistically significant. The same relation existed for waist circumference. Weight also displayed a similar trend, with a linear model best approximating the association in females and a second-order equation fitting the male data, but the test result for the sex \( \times \) weight interaction for the quadratic equations was nonsignificant. These quantitative trends were consistent with the graphic depiction in figure 1. In contrast to body mass index, waist circumference, and weight, waist: hip ratio displayed a linear association with intra-abdominal fat area and accounted for the same amount of variance in intra-abdominal fat area for both sexes. In men, intra-abdominal fat area increased more sharply with each unit of waist: hip ratio, as indicated by the sex-specific partial parameter estimate of 562.46 cm\(^2\) compared with 318.53 cm\(^2\) in women (in the model containing sex as both a confounding variable and an effect modifier, the \( p \) value for the interaction was 0.042). Despite the fact that subscapular skinfold thickness is an index of subcutaneous central fat deposition as well as an index of overall adiposity, the sex trends discussed for body mass index, waist circumference, and weight also appeared for this predictor, although the model \( R^2 \) was lower than that for the other anthropometric measures.

Table 4 mirrors the data presented in table 3, with subcutaneous fat area as the dependent variable, adjusted for age and atherosclerotic status for comparability with table 3. Unlike intra-abdominal fat area, associations of the same anthropometric variables with subcutaneous fat area were, with the exception of waist circumference, linear in both sex groups. The slopes of the regression curves did not differ by sex for either body mass index or waist: hip ratio. Waist circumference exhibited a slight quadratic trend in males; however, this trend was not statistically significantly different from the trend in females. The association between weight and subcutaneous fat area was approximated by a first-order equation, with subcutaneous fat area increasing more for women than for men with increasing body weight. Finally, subcutaneous fat area

![Table 3](https://academic.oup.com/aje/article-abstract/144/4/335/161559/161559.html)
also increased more sharply in females as subscapular skinfold thickness increased, relative to males (p for interaction = 0.0765).

To establish which conventional anthropometric variables best predicted intra-abdominal fat and subcutaneous fat areas, stepwise forward regression models were fitted for each set of measurements. Sex-specific models included the introduction of quadratic and first-order terms for anthropometric parameters as well as age, height, frame size (elbow breadth), and preclinical atherosclerosis, and used a p value of 0.05 as the criterion for a variable’s remaining in the model. For women, waist circumference was the variable selected to best predict intra-abdominal fat area (model \( R^2 = 0.428 \)), with no other variables significantly contributing to the model; of the variables tested, waist and hip circumferences were the only statistically significant predictors of subcutaneous fat area (\( R^2 = 0.755 \)). For men, waist : hip ratio and age were significant predictors of intra-abdominal fat area (\( R^2 = 0.329 \)), with none of the other anthropometric variables contributing further. Associations of subcutaneous fat area with anthropometric measures were more complex to estimate in males than in females, however. The parameters that best predicted the model variance in subcutaneous fat area were waist circumference\(^2\), triceps skinfold thickness, age\(^2\), hip circumference, and height (\( R^2 = 0.741 \)).

### DISCUSSION

The data presented for this subpopulation of participants from the ARIC Study suggest that the associations between intra-abdominal fat area and conventional anthropometric measures of general and central obesity differ by sex. In men, weight, body mass index, waist circumference, and subscapular skinfold thickness were related to intra-abdominal fat area in a nonlinear, quadratic manner, implying that greater intra-abdominal fat deposition rates occur in males at relatively low levels of the above indices. At higher levels of obesity, intra-abdominal fat deposition leveled off, with adipose tissue presumably accumulating more uniformly across storage sites. Among women, the association between intra-abdominal fat area and each of the anthropometric indices examined here was linear. Waist : hip ratio was the sole exception to the differential sex pattern, with a linear regression model providing the best fit with the intra-abdominal fat area data in both sexes. In spite of this similarity, men still appeared to deposit intra-abdominal fat at a greater rate than women relative to waist : hip ratio, as indicated by the greater model parameter estimate and the statistically significant interaction between sex and waist : hip ratio in predicting intra-abdominal fat area, and consistent with the other anthropometric associations. Conventional anthropometric measures predicted a moderate amount of the variance in intra-abdominal fat area values (20–46 percent) for both sexes, with skinfold thickness predicting the least.

The associations observed for intra-abdominal fat contrast with the results seen for subcutaneous fat. In both sexes, the associations between subcutaneous fat area and weight, body mass index, waist circumference, waist : hip ratio, and subscapular skinfold thickness were linear. Furthermore, while subcutaneous fat area was greater in females than in males, the rate of subcutaneous fat deposition (estimated by the slope of the linear regression curve) was comparable between the sexes for each anthropometric index, with the exception of body weight. In women, increasing weight appeared to lead to a greater rate of subcutaneous fat deposition than it did in men, as indicated by the statistically significant sex difference (p = 0.003) between the slopes of the regression equations. This trend was also suggested by the borderline significance of the sex \( \times \) subscapular skinfold interaction term when subscapular skinfold thickness was used to predict subcutaneous fat area. In general, each of the conventional anthropometric measures explained a greater proportion of the total variance in subcutane-

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**TABLE 4.** Relations between subcutaneous fat area (cm\(^2\)) and conventional anthropometric measures, Atherosclerosis Risk in Communities Study, 1990–1992†

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Partial β</th>
<th>p for sex x predictor interaction</th>
<th>p for sex x predictor interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Females</td>
<td>Males</td>
<td></td>
</tr>
<tr>
<td>Body mass index(§)</td>
<td>-21.75**</td>
<td>19.40**</td>
<td>0.302</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.682</td>
<td>0.565</td>
<td></td>
</tr>
<tr>
<td>Waist(²)</td>
<td>0.039</td>
<td>0.078*</td>
<td></td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>0.304</td>
<td>-8.36</td>
<td>&gt;0.80</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.601</td>
<td>0.696</td>
<td></td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>7.30**</td>
<td>7.02**</td>
<td>0.581</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.597</td>
<td>0.682</td>
<td></td>
</tr>
<tr>
<td>Weight (pounds)(II)</td>
<td>3.71**</td>
<td>2.46**</td>
<td>0.003</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.667</td>
<td>0.561</td>
<td></td>
</tr>
<tr>
<td>Waist : hip ratio</td>
<td>533.31*</td>
<td>800.66**</td>
<td>0.252</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.193</td>
<td>0.318</td>
<td></td>
</tr>
<tr>
<td>Subscapular skinfold (mm)</td>
<td>11.28**</td>
<td>7.71**</td>
<td>0.077</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.539</td>
<td>0.298</td>
<td></td>
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</table>

* p < 0.05; ** p < 0.001.
† Each separate model was adjusted for age and preclinical atherosclerosis status.
‡ Global F test for removal of all interaction terms (sex \( \times \) predictor) or sex \( \times \) predictor, or sex \( \times \) predictor.
§ Weight (kg)/height (m)\(^2\).
II 1 pound = 0.45 kg.
ous fat area than in intra-abdominal fat area, particularly the measures of generalized obesity (weight and body mass index). Waist : hip ratio, which is indicative of a central fat patterning tendency, predicted 19 percent of the variance in subcutaneous fat area compared with 33 percent of the variance in intra-abdominal fat area, suggesting that subcutaneous fat deposition at the waist is not directly related to a central fat patterning tendency. Waist : hip ratio predicted an equivalent amount of total variance for both subcutaneous and intra-abdominal fat areas in men, while subscapular skinfold thickness was relatively strongly related to subcutaneous fat area in women but only weakly associated in men. These results again point to the preferenceal central deposition of adipose tissue as deep abdominal fat in men (25).

To our knowledge, the results presented in this report are unique in that the subgroup was derived from a random sample of the general population that was free of either preexisting cardiovascular disease or a suspected condition (such as cancer) requiring computed tomographic scanning of the abdomen (21, 26–29). Other studies have focused strictly on obese individuals (14, 30, 31). Of the studies that have examined the association between intra-abdominal fat area derived by computed tomography or magnetic resonance imaging and that derived by conventional anthropometric measures in healthy populations, several have included only male participants.

Kekes-Szabo et al. (32) found that in 202 healthy white men aged 17–71 years, intra-abdominal fat area measured by computed tomography was highly correlated with minimum waist circumference \( (r = 0.80) \), while subcutaneous fat area was associated with body mass index \( (r = 0.80) \) and waist circumference at the umbilicus \( (r = 0.82) \). Ross et al. (33), examining 27 healthy middle-aged men, found that waist circumference was highly predictive of total abdominal adiposity by magnetic resonance imaging, while body mass index, age, and waist : hip ratio were the best predictors of intra-abdominal fat area, with the majority of the variance in intra-abdominal fat area being explained by body mass index and age. In a study of 24 men with body mass indices similar to those of the men in our group (21–34 vs. 20–35) but with a wider age range (25–55 years vs. 48–68 years), Seidell et al. (34) found that body mass index was correlated with peripheral fat measured by computed tomography \( (r = 0.91) \), while waist : hip ratio was highly correlated with intra-abdominal fat area \( (r = 0.88) \). These results were identical to ours for men, with waist : hip ratio and age predicting 33 percent of the variance in intra-abdominal fat area. We observed a slightly smaller correlation between waist : hip ratio and intra-abdominal fat area \( (r = 0.54) \), which may have been due to the narrower age range of our participants.

Several other studies have examined the association between intra-abdominal fat and anthropometric measures in healthy females. De Ridder et al. (5) found that in 24 adolescent (premenopausal) girls, waist circumference was a good predictor of intra-abdominal fat area by magnetic resonance imaging \( (r = 0.62) \). Fowler et al. (35) found a strong association between skinfold thickness and abdominal subcutaneous fat measured by magnetic resonance imaging in 14 young women. Armellini et al. (36), examining intra-abdominal fat area by computed tomographic scanning in 119 women with a wide range of ages (15–72 years) and body weights (body mass index = 24–51), found that while each successive tertile of visceral fat was significantly higher than the previous tertile, the waist : hip ratio could not distinguish between the two upper tertiles, suggesting both age and obesity differences in the measurement of intra-abdominal fat versus anthropometry. Enzi et al. (28) reported a strong age association relative to the subcutaneous fat area: intra-abdominal fat area ratio in a group of 62 males and 68 females (pre- and postmenopausal) ranging in age from 20 years to >60 years who had been referred for diagnostic computed tomography \( (r > 0.6) \) for both sexes. In our study, age was weakly correlated with intra-abdominal fat area in males \( (r = 0.242) \) but not in females; again, our group had a much narrower age range, with a potentially narrower range of estrogen and testosterone levels.

Although the majority of the females in this study were postmenopausal, they still exhibited markedly different fat deposition patterns than males, despite previous reports of fat deposition shifting from peripheral and subcutaneous to visceral with declining estrogen and progesterin levels (37, 38). Females had higher relative and absolute amounts of subcutaneous fat area than did males, while intra-abdominal fat area predominated in males; this is comparable to the results reported by Ross et al. (39) for android-obese men and women. Very few of the women in our study were on estrogen replacement therapy, but it appears that the central fat patterning displayed in this subgroup of women was both subcutaneous and visceral regardless of estrogen status, while men tended to deposit fat viscerally, particularly at relatively low body weights and body mass indices.

Limitations of our study include its cross-sectional design, which prevents assessment of temporality or causality. Furthermore, this middle-aged, predominately white sample somewhat limits the generalizability of our results, and the data may be biased by selective survival. However, the magnetic resonance...
imaging methodology used here has been shown to have high intra- and interreader repeatability (20). In addition, the anthropometric measurements were made by a standardized protocol used for the entire ARIC Study cohort, which included extensive training and evaluation for reliability. Finally, because fat accumulation is believed to shift from subcutaneous to visceral by late middle age in men and in postmenopausal women, these participants were at an appropriate age for measurement of visceral fat deposition.

A major goal of this report was to compare intra-abdominal fat area as a gold standard for visceral fat accumulation with indices that have often been used as surrogates for intra-abdominal fat. Ascertainment of these associations with more readily obtained measurements is of great value in large observational studies where the cost of equipment, the amount of time needed to image the visceral region, and the lack of portability make magnetic resonance imaging impractical. Several studies with smaller sample sizes than ours have attempted to generate predictive equations for intra-abdominal fat, subcutaneous fat, and total fat areas from conventional anthropometric areas. In general, total fat area is well predicted by weight and height (40, 41) in both sexes, while subcutaneous fat area can be approximated by body mass index and skinfold thickness (42). Prediction of intra-abdominal fat area appears to vary by sex, with body mass index, age, and either waist circumference or waist:hip ratio estimating a large percentage of the variance in intra-abdominal fat area among men (42, 43) and body mass index plus waist:thigh circumference ratio and menopausal status estimating a large percentage among women (42). Sjöström (41) found that for men, intra-abdominal fat volume increased linearly with total fat volume; for women, the correlation was low at total fat volumes below 30 liters, but the pattern was similar to men's among obese women. The multivariable stepwise linear regression analysis presented here suggested that in men, waist:hip ratio and age were the best predictors of intra-abdominal fat area; in women, waist circumference alone predicted intra-abdominal fat area. Subcutaneous fat area was well predicted by conventional techniques, as reflected by the impressively large $R^2$ values observed. Body mass index, which has been widely used as a marker of obesity, was associated with intra-abdominal fat area in a quadratic fashion for men. Therefore, investigations into the association between cardiovascular disease risk factors and obesity that have limited anthropometric data should consider a second-order approach to modeling these associations in men.

The heterogeneity of populations previously examined for intra-abdominal fat in the literature—e.g., obese participants, persons of widely ranging ages, cancer patients, or healthy volunteers with a limited sample size—has made extrapolation of observed associations to more general populations difficult. Our study had the advantage of having a larger sample size than many of the previous magnetic resonance imaging studies, derived from a well-defined population-based cohort within a focused age range. Although waist circumference and waist:hip ratio are relatively well correlated with intra-abdominal fat area in this middle-aged group (with correlation coefficients ranging from 0.45 to 0.65), additional studies should be conducted in younger cohorts to examine these associations in lean individuals with fewer competing risk factors. In particular, lean young men with a tendency toward intra-abdominal fat deposition may be at increased risk for hypertriglyceridemia, peripheral hyperinsulinemia, non-insulin-dependent diabetes mellitus, and hypertension because of the metabolic implications of intra-abdominal fat stores, and they are at an age where intervention could markedly reduce their future cardiovascular morbidity and mortality (3). The other group that would benefit from knowledge of the associations of intra-abdominal fat area with standard central fat surrogates is postmenopausal women. Different tendencies to deposit fat (as opposed to a peripheral distribution) may lead to the same conditions described above for lean young men; in addition, because females experience cardiovascular disease 10 years later than males, on average (44, 45), risk factor intervention, weight loss, and estrogen replacement therapy may also reduce subsequent risk in older women who are predisposed to android fat patterning.

In this study, greater intra-abdominal fat accumulation rates in lean men relative to women may present another biologically plausible explanation for some of the sex differences in cardiovascular risk seen at middle age. An understanding of the associations between relatively easily obtained surrogate measures for visceral fat and a gold standard will strengthen our ability to identify individuals who are at risk for cardiovascular disease. These results should also be replicated in minority populations.

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