Waist circumference and abdominal adipose tissue distribution: influence of age and sex

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ABSTRACT
Background: The influence of age and sex on the distribution of abdominal adipose tissue for a given waist circumference (WC) is unclear.

Objective: The objective was to investigate the influence of age and sex on total (TAAT), visceral (VAT), and abdominal subcutaneous (ASAT) adipose tissue for a given WC.

Design: Body composition was assessed by whole-body magnetic resonance imaging in 147 younger men (< 50 y), 83 older men, 171 younger (premenopausal) women, and 80 older (postmenopausal) women with a wide range (16–40; in kg/m²) of body mass indexes.

Results: Within each sex, the regression lines between WC and TAAT were not significantly different (P > 0.1) between younger and older groups. Collapsed across age groups, women had more TAAT for a given WC than did men; however, this difference was significantly reduced with increasing WC (P < 0.05). Within each sex, regression lines derived for WC and ASAT were not significantly different between younger and older groups (P > 0.1). Collapsed across age groups, women had 1.8 kg more ASAT for a given WC (P < 0.05) than did men across the range of WCs. Within each sex, older men and women had a significantly greater increase in VAT for a given WC (P < 0.05) than did younger men and women. Furthermore, independent of age group, the slopes for WC and VAT were significantly higher (P < 0.05) in men than in women.

Conclusions: These are significant sex differences in TAAT, VAT, and ASAT for a given WC. Furthermore, the relation between VAT and ASAT is substantially influenced by age. Am J Clin Nutr 2005;81:1330–4.

KEY WORDS Visceralfat, abdominal subcutaneous fat, sex, menopause, age, magnetic resonance imaging

INTRODUCTION
Previous studies have reported that, for a given waist circumference (WC), premenopausal (1) and postmenopausal (2) women have more abdominal subcutaneous adipose tissue (ASAT) than do men. However, it is unclear how sex alters the association between visceral AT (VAT) accumulation and WC. Pouliot et al (1) suggest that men and women have similar amounts of VAT for a given WC. In contrast, Schreiner et al (2) report that although older men generally have more VAT than do older women, this difference is diminished with increasing WC. Whether the disparate findings between these studies are explained by differences in age is unknown.

It is well known that age is positively associated with an increase in VAT, independent of sex (3, 4). The age-related increase in VAT is greater in men than in women; however, in women VAT accumulation increases rapidly after menopause to a rate similar to that of men (3). In contrast, subcutaneous AT has been reported to decrease with age in men (3). Whether this remains true in women is unclear because some studies have reported an age-related decrease in ASAT (4), whereas others have not (3). Accordingly, age-associated changes in abdominal AT distribution are not always reflected by a change in total abdominal AT (TAAT) or WC (4).

VC is a strong predictor of both VAT and ASAT (5). Given the independent contributions of VAT (6) and subcutaneous AT (7) in the development of metabolic risk, it is important to understand the influence of sex and age on abdominal AT distribution and its surrogate measure, WC. Thus, the purpose of this study was to examine the influence of sex and age on the relation between WC and abdominal AT accumulation in a large sample of Caucasian men and women with a wide range of age and adiposity. We hypothesized that advanced age would be associated with greater VAT deposition for a given WC independent of sex. Further, we speculated that men would have greater VAT and less ASAT than women for a given WC.

SUBJECTS AND METHODS
Subjects
Subjects consisted of 483 healthy white men (n = 232) and premenopausal (n = 171) and postmenopausal (n = 80) women who participated in various body-composition studies at Queen’s University (Kingston, Canada) and St Luke’s–Roosevelt Hospital (New York). The subjects varied widely in age (18–84 y) and body mass index (BMI; in kg/m²: 16–40). Three hundred forty-five subjects from Queen’s University and 136 subjects from Queen’s University were examined by magnetic resonance imaging in 147 younger men (< 50 y), 83 older men, 171 younger (premenopausal) women, and 80 older (postmenopausal) women.
Columbia University were recruited from among hospital employees, students at local universities, and the general public through posted flyers and the local media. Menopausal status was determined by self-report. The men were divided into younger (n = 147) and older (n = 83) groups by using a cutoff age of 50 y to facilitate comparisons between older men and (postmenopausal) women and younger men and (premenopausal) women across a similar age range. All participants gave informed consent before participation in accordance with the ethical guidelines of the respective institutional review boards.

**Anthropometric measurements**

Body mass was measured to the nearest 0.1 kg on a calibrated balance. Standing height was measured to the nearest 0.1 cm with a wall-mounted stadiometer. WC was taken at the level of the last rib to the nearest 0.1 cm after a normal expiration.

**Measurement by magnetic resonance imaging**

Whole-body tissue quantification was determined by using magnetic resonance imaging data acquired with a General Electric 1.5-Tesla magnet (Milwaukee, WI) by using an established protocol described in detail elsewhere (8). Once acquired, the data were analyzed with an image analysis program (TomoVision, Montreal, Canada) as described previously (8, 9); ≈41 equidistant images (1-cm-thick images, 4-cm spaces between images) were used to determine the tissue volumes. VAT and ASAT were calculated by using the 5 images extending from 5 cm below to 15 cm above L4–L5. Volume units (L) were converted to mass units (kg) by multiplying the volumes by the assumed density constants for AT (0.92 kg/L) (10).

**Statistical analyses**

Group data are presented as group means ± SDs. Analysis of variance was used to determine group differences in subject characteristics. Bonferroni adjustments were used for all post hoc multiple-group comparisons. General linear modeling was used to determine group-specific multivariate regressions between the various study variables. Sex, age, WC, and the interaction effects were used in the multiple regression analyses. Quadratic terms were also tested in the model for WC. Models were tested first for significant age group, sex, and WC interactions. If the three-factor interaction effect was significant, further analyses were conducted within each sex separately. If the three-factor and age interaction terms were not significant, a single

### TABLE 1

| Age (years) | 36.2 ± 8.0<br>Older men (n = 83) | 60.5 ± 8.7<br>Younger men (n = 171) | 37.6 ± 8.6<br>Older women (n = 80) | 66.7 ± 8.0<br>Younger women (n = 230) |
| BM (kg/m²) | 28.7 ± 4.5 | 29.3 ± 3.8 | 29.2 ± 5.6 | 27.5 ± 4.7 |
| Waist circumference (cm) | 97.9 ± 13.4 | 104.4 ± 11.1 | 89.6 ± 14.4 | 88.5 ± 13.0 |
| Body fat (%) | 25.9 ± 7.8 | 29.4 ± 6.3 | 39.1 ± 9.5 | 38.9 ± 8.1 |
| AT (kg) | | | | |
| Visceral | 2.34 ± 1.44 | 3.92 ± 1.84 | 1.49 ± 1.01 | 1.71 ± 1.11 |
| Abdominal subcutaneous | 3.57 ± 1.79 | 3.61 ± 1.28 | 4.38 ± 2.29 | 4.14 ± 1.78 |
| AT area at L4–L5 (cm²) | 115.1 ± 66.1 | 193.3 ± 88.1 | 86.4 ± 56.4 | 102.3 ± 63.5 |
| Abdominal subcutaneous | 239.0 ± 115.3 | 244.8 ± 86.8 | 301.9 ± 153.8 | 288.6 ± 124.6 |

The solid line represents the regression line for men (○; n = 230) and the broken line that for women (●; n = 251). TAAT<sub>men</sub> (kg) = −14.5 + 0.21(WC), TAAT<sub>women</sub> (kg) = −10.1 + 0.18(WC).

The solid line represents the regression line for men (○; n = 230) and the broken line that for women (●; n = 251). ASAT<sub>men</sub> (kg) = −7.57 + 0.11(WC), ASAT<sub>women</sub> (kg) = −5.74 + 0.11(WC).
model was used to determine sex differences in slope and intercept collapsed across age group. The study variables were normally distributed, and residual analyses were performed to determine significant points of influence in the final models. Significant outliers with large jackknife residuals and high leverage were excluded from the analyses. To allow for comparisons between premenopausal and postmenopausal women, values were age standardized to 50 y of age. There was a significant menopausal status × WC interaction (P < 0.05). The solid line represents premenopausal women (n = 171) and the broken line represents postmenopausal women (n = 80). VAT_premenopausal_women (kg) = −0.14 + 0.0045(WC) − 0.099(age) + 0.0014(age × WC). VAT_postmenopausal_women (kg) = −8.01 + 0.115(WC) + 0.050(age) + 0.0006(age × WC).

RESULTS

Subject characteristics are presented in Table 1. BMI was not significantly different (P > 0.05) between any of the 4 groups. As expected, both groups of women had a significantly greater (P < 0.05) percentage body fat but a lower WC and less VAT than did the men. Although the older men had a significantly greater (P < 0.05) WC and more VAT than did the younger men, the younger and older women did not differ significantly in any of the body-composition measures.

Age was positively associated with WC, VAT, and ASAT only in the younger groups of men and women (data not shown). Therefore, statistical adjustment for age was restricted to sex comparisons between the younger men and women.

The three-factor interaction (age × sex × WC) effect was not significant (P > 0.05). However, there was a significant sex effect but no age-group interaction effect (P > 0.05) on the relation between WC and TAAT (P < 0.05). Collapsed across the age groups, women had more abdominal AT for a given WC than did men; however, this difference was significantly reduced (P < 0.05) with increasing WC (Figure 1). Age was not a
significant covariate ($P > 0.05$) in any of the models for WC and abdominal AT.

The three-factor interaction (age $\times$ sex $\times$ WC) effect was not significant for ASAT ($P > 0.05$). There was a significant sex effect but no age-group interaction effect ($P > 0.05$) on the relation between WC and ASAT ($P < 0.05$). Collapsed across the age groups, women had 1.8 kg more ($P > 0.05$) ASAT for a given WC than did men across the range of WC values (Figure 3).

There was a significant three-factor interaction (age $\times$ sex $\times$ WC) effect ($P < 0.05$); thus, VAT analyses were performed within each sex separately. Within each sex, the slope of the regression lines between WC and VAT were significantly greater in the older men and women than in the younger men and women ($P < 0.05$). Thus, for a given increase in WC, men had a greater increase in VAT than did the women. Furthermore, independent of age group, the slope of the regression line between WC and VAT was higher ($P < 0.05$) in men than in women (Figure 3A and B). After age was included in the model, younger men continued to have a higher slope for the association between WC and VAT than did younger women (Figure 3C).

The postmenopausal women continued to have a greater increase ($P < 0.05$) in VAT for a given increase in WC (ie, higher slope) after control for age, and the difference increased with increasing WC. The relation between WC and VAT standardized to 50 y of age is shown in Figure 3D.

The predicted VAT mass values for WC cutoffs associated with increased health risk in men and women are given in Table 2. Given the common use of the L4–L5 landmark for determination of abdominal AT deposition with the use of radiographic methods, VAT values ($cm^2$) at L4–L5 are also provided.

**DISCUSSION**

The findings of this study show that significant sex differences exist in TAAT, VAT, and ASAT deposition for a given WC. Although our findings confirmed that women have significantly more ASAT than do men for a given WC, in contrast with the findings of others, we observed that VAT deposition was significantly higher in men than in women. Furthermore, we showed that menopausal status influences VAT deposition for a given WC beyond that of age per se. Moreover, the influence of age on VAT deposition is different between older and younger persons. These findings suggest that, for a given WC, sex, age, and menopausal status need to be considered when predicting abdominal AT distribution and associated health risks.

Contrary to previous observations (1, 2), we observed that, independent of age, VAT deposition is significantly higher in men than in women for a given WC, and the difference was magnified with increasing WC. Pouliot et al (1) report that younger men and women have similar amounts of VAT for a given WC. In older men and women, Schreiner et al (2) report a curvilinear relation between WC and VAT, wherein men generally have more VAT than do women, although the difference is attenuated with increasing WC. The discrepant findings are not readily explained but may be due in part to differences in the landmark used for the WC measurement, because WC was determined at the last rib in this study, at the waist narrowing in the study by Pouliot et al (1), and at the umbilicus in the study by Schreiner et al (2). Wang et al (11) report that although the difference between WC measurement sites is relatively small in men ($\approx 1$ cm), in women a difference of $\approx 5$ cm is observed between the smallest (minimal waist) and largest (iliac crest) measurement sites. Thus, differences in the WC measurement site may have influenced the sex differences in the pattern of VAT deposition observed. Nevertheless, it is clear that the influence of sex on the relation between VAT and WC requires further investigation.

That menopausal status influences the relation between WC and VAT distribution in women beyond the effect of age per se is noteworthy. In other words, for a given WC, postmenopausal women have more VAT than do premenopausal women even after age is controlled for. This is in contrast with a study by Han et al (12) that failed to show a difference in VAT deposition for a given WC in a small cohort of women above ($n = 19$) and below ($n = 15$) 50 y of age. Nevertheless, several other studies have also shown a preferential accumulation in VAT in postmenopausal women (3, 4, 13). It is suggested that these body-composition changes are in part due to alterations in sex hormone concentrations that are associated with menopause (14–16). Indeed, ovarian hormone–deficient women have a significantly higher rate of
fatty acid uptake in the VAT depot than do premenopausal women (16). Furthermore, it has been reported that hormone replacement therapy attenuates the propensity to increase VAT (15). Together, these findings suggest that menopausal status should be considered when developing WC cutoffs for abdominal obesity–related metabolic risk.

It is known that WC is a strong predictor of metabolic risk, independent of BMI (17). Current evidence suggests that WC should be considered when developing WC cutoffs for abdominal obesity–related metabolic risk.

Whether age-related changes in VAT influence the interpretation of health risk for a given WC is unknown. Limitations of this study warrant mention. First, our findings are restricted to white men and women. Because racial differences in body fat distribution are clearly established (23), it is unclear whether the pattern or magnitude of sex and age-related changes in VAT limits for a given WC would be similar in other races. Second, this study did not control for differences in cardiorespiratory fitness. It has been shown that, for a given WC, fit men have lower amounts of visceral adiposity than do unfit men (24). Because this was a cross-sectional study, we cannot make causal or temporal inferences about the pattern of VAT or VAT deposition for a given increase in WC. It is also unclear whether our results were influenced by a selection bias, because individuals who continued to increase abdominal adiposity throughout their life span may have developed disease and would have been excluded from participation in this study.

In summary, our findings showed that, for a given WC, abdominal AT distribution differs between the sexes. We confirmed that, for a given WC, women tend to have more VAT than do men, independent of age. Contrary to previous observations, men have more VAT than do women for a given WC. Furthermore, we showed that VAT accumulation for a given WC is also influenced by age and menopausal status. These findings suggest that AT distribution for a given WC is altered substantially by age and sex. Whether age-related changes in VAT influence the interpretation of health risk for a given WC is unknown.

JLK and SL performed the data analysis. JLK, SL, and RR wrote the manuscript. SBH aided in the interpretation and presentation of the results. None of the authors declared any conflicts of interest.

REFERENCES