Smaller differences in total and regional adiposity with age in women who regularly perform endurance exercise

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1Human Cardiovascular Research Laboratory, Center for Physical Activity, Disease Prevention and Aging, Department of Kinesiology and Applied Physiology, University of Colorado, Boulder 80309; and 2Divisions of Cardiology and Geriatric Medicine, Department of Medicine, University of Colorado Health Sciences Center, Denver, Colorado 80262

Van Pelt, Rachael E., Kevin P. Davy, Edie T. Stevenson, Teresa M. Wilson, Pamela P. Jones, Christopher A. DeSouza, and Douglas R. Seals. Smaller differences in total and regional adiposity with age in women who regularly perform endurance exercise. Am. J. Physiol. 275 (Endocrinol. Metab. 38): E626–E634, 1998.—Our aim was to determine if women who regularly perform endurance exercise demonstrate age-related elevations in body mass and adiposity. Ninety-five healthy females were studied: premenopausal (n = 28; mean ± SE age 30 ± 1 yr) and postmenopausal (n = 31; 56 ± 1 yr) endurance-trained runners and premenopausal (n = 17; 29 ± 1 yr) and postmenopausal (n = 19; 61 ± 1 yr) sedentary controls. In the runners, body mass did not differ across age, but percent fat and fat mass were higher (P < 0.05) in the postmenopausal women. The age-related difference in total body fat, however, was only ~50% as great (P < 0.01) as that observed in the sedentary controls due in part to smaller age-related differences in central ( truncal) fat. The higher fat mass in the postmenopausal runners was modestly (inversely) related to both exercise volume (r = −0.44, P < 0.01) and maximal oxygen consumption (r = −0.41, P < 0.01). The present findings provide experimental support for the hypothesis that women who regularly engage in vigorous endurance exercise may not gain body weight, undergo only a modest increase in total body fat, and do not demonstrate a significant elevation in central adiposity with age.

body composition; obesity; females

BODY MASS, TOTAL BODY FAT, and central adiposity all increase with age in sedentary adult women (7, 9, 14), and these increases appear to be greater than those observed in men (20). The increases in body weight and whole body and central adiposity with age are associated with an elevated risk of morbidity and premature mortality from cardiovascular and metabolic diseases (1, 6, 12). As such, the question of whether these adverse changes are inevitable consequences of the aging process or are modulated by lifestyle behaviors is of fundamental importance.

Regular exercise, especially involving activities associated with high levels of energy expenditure (i.e., “endurance” exercise), is one lifestyle factor that may affect age-related changes in body composition (11). In this context, an important question is whether women who regularly perform endurance exercise demonstrate increases in body mass and fatness with advancing age. Based on the available experimental data from our laboratory (5) and others (13, 23), however, the answer is not clear.

If whole body adiposity increases with age even in highly physically active women, there would seem to be at least two important related issues. The first would be to identify the regional sites contributing to the increase in total fat mass. The second would be to gain insight into the factors that may play a role in the age-related increases in adiposity. Regarding the latter, it has been proposed that declines in the amount of exercise performed (i.e., exercise-related energy expenditure) may contribute to age-associated elevations in body fatness in highly active women (13). Currently, however, there is no information concerning this issue.

Accordingly, the primary experimental objective of the present investigation was to determine if healthy women who regularly perform endurance exercise demonstrate age-related elevations in body mass and whole body adiposity. If so, important secondary goals were to determine 1) if the age-related elevations are smaller than those observed in sedentary healthy women; 2) the relative contributions of increases in central adiposity and fat in other regions; and 3) the role of age-associated declines in exercise volume.

METHODS

Subjects

We studied 95 healthy women aged 18–37 or 49–73 yr: 17 premenopausal and 19 postmenopausal sedentary women and 28 premenopausal and 31 postmenopausal distance runners. The pre- and postmenopausal runners were matched for age-adjusted competitive performance (both groups = 76 ± 1% of age-adjusted world record times) as described previously by our laboratory (8) and had been running for 9 ± 1 and 18 ± 2 yr, respectively.

Postmenopausal status of women was documented by plasma follicle-stimulating hormone levels exceeding 30 mU/ml and absence of menses. These subjects had been postmenopausal for at least 2 yr, and approximately one-half of each group was taking estrogen-based hormone supplements (10 sedentary, 13 runners). All subjects were healthy as assessed by medical history. Postmenopausal subjects were further evaluated for clinical evidence of cardiopulmonary disease with a physical examination and electrocardiograms during rest and maximal exercise. All subjects were Caucasian, well educated, of middle-class to upper-middle-class income status, and were nonsmokers.

The nature, purpose, and risks of the study were explained to each subject before written informed consent was obtained.
The experimental protocol was approved by the Human Research Committee at the University of Colorado at Boulder.

Body Mass and Composition

Total body mass was measured to the nearest 0.1 kg on a physician's balance scale (Detecto, Webb City, MO). Body mass index (BMI) was calculated from weight and height (kg/m²). Total body density was determined by hydrodensitometry as outlined by Brozek et al. (3). Residual volume of the lungs was measured using the oxygen dilution technique as previously outlined by Wilmore (33). Body fat percentage (%fat) was then calculated using the equation of Brozek et al. (3). Fat mass and fat-free mass were estimated from percent fat and body mass based on the two-compartmental model.

To gain as much insight as possible into age-related differences in regional adiposity, the following three different approaches were employed. 1) Skinfold thicknesses were measured at five sites (tricep, subscapular, suprailiac, abdomen, and thigh) by a single investigator to the nearest 1 mm using a Lange caliper (Cambridge Scientific); the average of the three trials was used (16). A small number of postmenopausal women (exercising group, n = 5; sedentary, n = 5) were unable or unwilling to perform the underwater weighing procedure. Thus their percent body fat was predicted from their skinfold measures based on the regression between procedure. Thus their percent body fat was predicted from

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The following three measures of central adiposity were used: 1) abdominal and suprailiac skinfold thicknesses (13); 2) waist circumference, which has been validated against computed tomographic (CT) and magnetic resonance imaging measures of abdominal adiposity (2, 10, 29); and 3) DEXA-derived truncal fat, which correlates strongly ($r = 0.90$) with CT-derived measurements of abdominal fat (26, 29).

Maximal Aerobic Capacity

Maximal oxygen consumption ($V_{\text{O}_{2}\text{max}}$) was used as a measure of maximal aerobic exercise capacity and was determined during incremental treadmill exercise using an on-line computer-assisted open-circuit spirometry system as previously described in detail (8). $V_{\text{O}_{2}\text{max}}$ values are presented in Tables 1–3 adjusted for body mass (kg) and fat-free mass (kg) using analysis of covariance, as well as in the standard ratio form ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) in the text.

Exercise Training Volume and Habitual Physical Activity

Weekly running mileage was used as a measure of exercise training volume in the regularly exercising women (8, 27). To determine possible age-related differences in habitual physical activity in the sedentary women, daily energy expenditure was estimated using the Stanford Physical Activity Questionnaire (24) as previously described by our laboratory (19).

Estimated Energy Intake

Energy intake was estimated from 4-day food records as described in detail previously (30). The same registered dietitian instructed all subjects and analyzed all food records using the Nutritionist IV (version 3.5.2; Hearst, San Bruno, CA) computer software program. Food records were analyzed for 12 premenopausal and 13 postmenopausal sedentary women and for 9 premenopausal and 15 postmenopausal runners.

Statistics

Group differences among the dependent variables were determined by two-way analysis of variance. A Newman-Keuls post hoc test for multiple comparisons was used to determine differences among specific comparisons. A significant interaction was interpreted to indicate that the age-related differences in body mass and composition were significantly different between the sedentary and exercising subject groups. Simple univariate regression analyses were performed to examine relations of interest. Simple unpaired $t$-tests were used to determine age-related differences in adiposity between the subgroups of exercising women matched for a particular factor of interest. In the postmenopausal women, there was no relation between hormone replacement status and any dependent variable; thus, users and nonusers were pooled within the sedentary and exercising groups. Statistical significance was set at $P < 0.05$. Data are presented as means $\pm$ SE.

RESULTS

Age-Related Differences in the Regularly Exercising Women

In the main subject groups (Table 1), $V_{\text{O}_{2}\text{max}}$ (55.0 $\pm$ 0.9 vs. 41.9 $\pm$ 1.5 ml · kg$^{-1}$ · min$^{-1}$) and exercise volume were lower, and estimated energy intake tended to be lower ($P = 0.09$) in the postmenopausal compared with the premenopausal runners. There were no age group differences in macronutrient composition, including alcohol consumption. Body mass, BMI, and fat-free mass were not significantly different between the two age groups, whereas percent body fat and fat mass were higher in the postmenopausal runners (Table 2). There were no significant age-related differences in waist circumference or regional skinfold thicknesses (Table 2).

The lack of age-related differences in fat-free mass as well as the higher percent body fat and fat mass in the postmenopausal runners were confirmed in the subjects who were assessed by DEXA (Table 3). Bone mineral density was not different in the two age groups (Table 3). Regional analysis of the DEXA scan (Fig. 1) revealed that the postmenopausal runners tended to have greater leg fat; however, neither arm fat nor trunk fat was significantly different in the two age groups.

Age-Related Differences in the Healthy Sedentary Controls: Comparison With the Exercising Women

In the main groups of sedentary women, habitual physical activity levels were similar, $V_{\text{O}_{2}\text{max}}$ was lower
density was not different across age in the sedentary women (Table 3). Regional analysis of the DEXA scans (Fig. 1) indicated that the postmenopausal sedentary women had greater leg, trunk, and arm fat compared with the premenopausal women.

In the main subject groups, the age-associated differences in percent body fat (~50%), fat mass (~150%), waist circumference (~450%), and abdominal, supra-iliac, and subcapular skinfold thicknesses (~300–800%) were greater in the sedentary controls compared with the runners (Table 2). In the DEXA subgroups, the age-related difference in trunk fat was greater (~100%) and the difference in arm fat tended to be greater (~60%) in the sedentary controls compared with the exercising women (Fig. 1).

Relation Between Exercise Volume and Whole Body Adiposity in the Regularly Exercising Women With Age

Univariate correlations performed on the pooled main group of regularly exercising women revealed that exercise volume was inversely related to percent body fat ($r = -0.45$) and fat mass ($r = -0.44$; both $P < 0.01$).

In light of these relations, subgroups of pre- and postmenopausal runners (each $n = 17$) matched for exercise volume (31.3 ± 1.3 vs. 30.1 ± 0.8 miles/wk, not significant) were compared. Percent body fat and fat mass were greater in the postmenopausal exercise volume-matched runners (Fig. 2, A and B).

Relation Between VO$_{2\text{max}}$ and Whole Body Adiposity in the Regularly Exercising Women With Age

Because differences in exercise volume failed to explain the age-related differences in whole body adiposity in the runners, we sought to determine the possible relation with maximal aerobic capacity. To express maximal aerobic capacity, we used absolute (l/min) VO$_{2\text{max}}$ corrected for fat-free mass rather than total body mass, because whole body adiposity contributes directly to the latter but not the former. On the basis of univariate correlations, VO$_{2\text{max}}$ was inversely related to percent body fat ($r = -0.57$) and fat mass ($r = -0.41$;...
both P = 0.001). On the basis of these significant relations, we then compared subgroups of premenopausal (n = 17) and postmenopausal (n = 21) runners with similar mean VO2max (2.67 ± 0.05 vs. 2.60 ± 0.05 l/min, not significant). Within these subgroups, percent body fat and fat mass were greater in the postmenopausal VO2max-matched runners (Fig. 2, C and D).

Other Relations of Interest

Within the pooled regularly exercising women, exercise volume correlated modestly (r = −0.23 to −0.35, all P < 0.05) with regional skinfold thicknesses and waist circumference. In contrast, neither VO2max nor age-adjusted competitive running performance was significantly related to any of these measures of regional adiposity. Among the pooled sedentary women, neither habitual physical activity levels nor VO2max was significantly related to any measure of regional or whole body adiposity. Estimated caloric intake was not related to any measure of adiposity in either population.

Relation Between Hydrodensitometry- and DEXA-derived Measurements of Body Composition

The age-related differences in whole body composition as determined by hydrodensitometry compared with DEXA are shown in Fig. 3. The age-related differences in percent body fat, fat mass, and fat-free mass in both the sedentary and the endurance-trained women were similar with both methods. Thus, in the present study, hydrodensitometry and DEXA provided the same information on whole body composition for healthy women varying widely in age and habitual exercise status.

DISCUSSION

The major findings from the present study are as follows. First, body mass is not different but whole body adiposity is higher with age even in women who regularly perform vigorous endurance exercise. Second, the age-related elevation in total body fat in these active women is much smaller than that observed in healthy sedentary adult women. Third, in contrast to sedentary women, central adiposity does not differ significantly across age in women who perform high levels of endurance exercise, and this contributes to their smaller age-associated elevation in total body fatness. Fourth, neither declines in the amount of exercise performed nor in maximal aerobic capacity explain the age-associated elevations in whole body adiposity in these highly physically active women.

Body Mass and Whole Body Adiposity With Age in the Exercising Women

The results of the present study demonstrate an absence of age-related differences in body mass in women who regularly perform endurance exercise. These findings are in agreement with the results of recent cross-sectional studies from our laboratory (5) and others (23) which, taken together, support the concept that, on average, body weight does not increase significantly with age in this population. The present findings also are supported by data from recent longitudinal studies showing no increases in body mass with age in men who are able to maintain high levels of exercise training (21).

Our observations do, however, indicate that whole body adiposity increases with age in these active women. The average age-related elevations in total body fat observed in the exercising women in the present study (i.e., 8% body fat and ~5 kg fat mass) are almost identical to the mean differences in percent body fat (8–9%) and fat mass (5–6 kg) reported in an earlier cross-sectional study by Kohrt and colleagues (13). These findings differ from those in our recent study on young and middle-aged adult female distance runners in which we found no age-associated differences in total body fat (5). The differences likely are due to the absence of subjects >56 yr of age in our previous investigation. Considered together, the results of the present study and those of Kohrt et al. (13) advance the idea that some increase in total adiposity occurs with age even in highly physically active women.

Comparison With Sedentary Women

Although an age-related elevation in fat mass was observed in the runners in the present study, the difference was less than one-half of that noted in the healthy sedentary women (Table 2). Our results are consistent with the age-associated differences in whole body fatness in these two populations reported previously by Kohrt and colleagues (13). Thus, together these observations provide experimental support for the idea that, compared with healthy sedentary women, the increases in total adiposity with advancing age are much smaller in women who regularly engage in vigorous endurance exercise. We should point out, however, that the ratios of either percent body fat or fat mass in premenopausal compared with postmenopausal women were similar in the exercising and

| Table 3. Subject characteristics and body composition for the DEXA subgroups |
|---------------------------|---------------------------|---------------------------|---------------------------|
|                        | Sedentary Women           | Endurance-Trained Women   |
|                        | Premeno-pausal            | Postmeno-pausal           | Premeno-pausal            | Postmeno-pausal           |
|                        | (n = 9)                   | (n = 11)                  | (n = 9)                   | (n = 11)                  |
| Age, yr Body mass, kg  | 27 ± 2                    | 60 ± 2*                   | 33 ± 1                    | 60 ± 2*                   |
| BMI, kg/m²             | 61.8 ± 2.1                | 67.7 ± 3.7                | 56.2 ± 2.0                | 60.0 ± 1.4                |
| Body fat, %            | 30.1 ± 2.6                | 38.7 ± 2.5*               | 16.6 ± 1.2†               | 23.3 ± 1.7†               |
| Fat mass, kg           | 18.8 ± 2.1                | 26.8 ± 2.8*               | 9.4 ± 1.0†                | 14.1 ± 1.1†               |
| Fat-free mass, kg      | 43.0 ± 1.5                | 41.0 ± 2.0                | 46.8 ± 1.4                | 46.0 ± 1.3                |
| BMD, g/cm²             | 1.21 ± 0.02               | 1.17 ± 0.02               | 1.21 ± 0.02               | 1.15 ± 0.03               |

Values are means ± SE; n, no. of subjects. BMD, bone mineral density. *P < 0.05 vs. premenopausal group (same activity level); †P < 0.05 vs. sedentary group (same age).
sedentary subject groups. This may reflect, at least on a relative basis, some common influence of age on the regulation of total adiposity in the two populations.

Age-Related Differences in Regional Adiposity

How do the age-related differences in regional adiposity observed in the present study help explain 1) the higher total adiposity in the postmenopausal compared with the premenopausal exercising women and 2) the smaller difference in total adiposity with age in the exercising compared with the sedentary women?

Concerning the first question, we found no statistically significant age-related differences in waist circumference, regional skinfold thicknesses, or DEXA-derived arm, trunk, or leg fat in the exercising women. However, close inspection of the skinfold (Table 2) and regional DEXA (Fig. 1) data indicate that the absolute mean skinfold thicknesses at several sites as well as fat

Fig. 1. Mean ± SE values for arm fat (A), trunk fat (B), and leg fat (C), as measured by dual-energy x-ray absorptiometry (DEXA) in subgroups of the pre- and postmenopausal sedentary (S) and endurance-trained (ET) women. Age-related differences (kg) are shown on right. ns, Not significant.
mass in all three measured regions were directionally, although not significantly, higher in the postmenopausal compared with the premenopausal runners. More specifically, based on our DEXA results, the ~5 kg age-related difference in total fat mass in the two age groups was accounted for by ~0.5, 2.5, and 2.0 kg mean differences in fat mass in the arms, trunk, and legs, respectively. Thus the most likely explanation for the higher total body fat in the middle-aged and older exercising women is slightly greater adiposity in both the upper- and lower-body regions.

With regard to the second question, we found that the age-related differences in waist circumference (Table 2), skinfold thickness at several sites (abdominal, subscapular, and suprailiac), and trunk fat (DEXA) all were significantly smaller in the exercising women. Moreover, the age-associated differences in triceps skinfold thickness and arm fat tended to be less in the physically active women. In contrast, the age group differences in thigh skinfold thickness and leg fat were not different in the sedentary and exercising women. These data indicate that the smaller age-related difference in total body fatness in the active women was associated primarily with smaller differences in central adiposity and possibly arm fat compared with the sedentary controls.

Role of Exercise Volume and Other Factors in the Age-Related Differences in Whole Body Adiposity in the Exercising and Sedentary Women

Exercise volume. Recently, it was reported that leisure time physical activity is a significant (inverse) physiological correlate of whole body adiposity among healthy men and women of increasing age (20). Moreover, results of recent longitudinal studies in male runners suggest that marked declines in exercise training volume are associated with greater age-related increases in body fat (21, 28). Therefore, it would seem reasonable to postulate, as Kohrt and colleagues (13) have done previously, that the elevations in total adiposity with age in active women are related to declines in exercise-related energy expenditure.

On the basis of our univariate correlations, our data indicate that the average weekly amount of endurance exercise performed explained only ~20% of the overall variance in total body fat in our pooled sample of physically active women. This observation of only a
A moderate relation between the two variables was supported by the subsequent finding that percent body fat and fat mass remained significantly greater in a subsample of postmenopausal runners matched for weekly running mileage with premenopausal runners. Thus our results are consistent with the view that relatively modest declines in exercise volume at best play only a small role in the age-related elevations in whole body adiposity in healthy women who exercise regularly. This is supported by recent observations from both cross-sectional (32) and longitudinal studies in men showing that whole body adiposity increases significantly with age despite maintenance of high levels of endurance exercise (21, 28).

Non-running-related physical activity. Another possibility is that a lower energy expenditure related to physical activity other than running may have contributed to the higher total fat in the postmenopausal exercising women. We did not measure this in the present study and, therefore, it remains a possibility.

Resting metabolic rate. Recently, we demonstrated that mean resting metabolic rate was slightly, but not significantly, lower in middle-aged and older compared with young adult physically active females (30). Most importantly, the age-related difference in resting metabolic rate was much greater in sedentary than in exercising women. As such, it is possible that a subtle decline in resting energy expenditure contributed to the elevation in total body fat across age in the active women in the present study. Alternatively, the lack of any significant age-related reduction in resting metabolic rate in exercising women may play a significant role in their smaller difference in whole body adiposity with age compared with the sedentary women.
Energy intake and composition. As noted previously (13), elevations in total body fat across age within the physically active women, as well as between the active and sedentary women, could be related in part to energy intake. In the present study, there were no significant relations between total caloric intake or diet composition estimated from diet records and measures of whole body adiposity in either the exercising or the sedentary women. In addition, estimated energy intake tended to be lower with age in both the active and the sedentary women (Table 1), and the magnitude of the differences (−17 vs. 14%) was similar despite a smaller age-related difference in fat mass in the former. Thus our data do not support a clear role for energy intake in explaining differences in total adiposity within or between these subject groups.

Energy balance. It is important to note that increases in total body fat, in either the sedentary or the physically active women, would not be due solely to changes in either energy expenditure or energy intake but rather to changes in energy balance. That is, age-related increases in adiposity may occur due to reductions in energy expenditure that are proportionately greater than reductions in energy intake. A better ability to match changes in energy intake to changes in energy expenditure with age could contribute to the smaller age-related differences in adiposity in the physically active compared with the sedentary women. However, our measurements of energy expenditure and energy intake are not sensitive enough to address this possibility directly.

Limitations

The main limitation of the present study is the cross-sectional design employed. As with all cross-sectional studies, it is possible that genetic factors and/or other lifestyle behaviors, including dietary practices, influenced the results of our group comparisons. We attempted to minimize these potential influences by matching our pre- and postmenopausal runners for age-adjusted performance (relative constitutional elite-performance matching our pre- and postmenopausal runners for age-adjusted performance (relative constitutional elite-performance matching our pre- and postmenopausal runners for age-adjusted performance (relative constitutional elite-performance matching our pre- and postmenopausal runners for age-adjusted performance (relative constitutional elite-performance matching our pre- and postmenopausal runners for age-adjusted performance (relative constitutional elite-performance matching our pre- and postmenopausal runners for age-adjusted performance (relative constitutional elite-performance matching our pre- and postmenopausal runners for age-adjusted performance (relative constitutional elite-performance matching our pre- and postmenopausal runners for age-adjusted performance (relative constitutional elite-performance matching our pre- and postmenopausal runners for age-adjusted performance (relative constitutional elite-performance matching our pre- and postmenopausal runners for age-adjusted performance (relative constitutional elite-performance matching our pre- and postmenopausal runners for age-adjusted performance (relative constitutional elite-performance matching our pre- and postmenopausal runners for age-adjusted performance (relative constitutional elite-performance matching our pre- and postmenopausal runners for age-adjusted performance (relative constitutional elite-performance matching our pre- and postmenopausal runners for age-adjusted performance (relative constitutional elite-performance matching our pre-

Significance

There are several important biomedical implications of our findings. First, obesity and weight gain are associated with the development of non-insulin-dependent diabetes (4), coronary heart disease (31), and stroke (22) as well as with elevated overall premature mortality (17) in women. The apparent lack of body weight gain and smaller elevation in whole body adiposity across age in the exercising women may contribute to the lower age-related increases in morbidity and premature mortality observed in physically active women (15). Second, central adiposity appears to be the most clinically important expression of adiposity with respect to risk of chronic degenerative diseases (6, 12). As such, the absence of significant age-related elevations in central adiposity in women who exercise regularly, as suggested by the results of the present study, may play an important role in their reduced risk of developing chronic diseases with advancing age (15).

Conclusions

The present findings provide experimental support for the idea that, in marked contrast to sedentary adult females, women who regularly engage in vigorous endurance exercise may not gain body weight, undergo only a modest increase in total body fat, and do not demonstrate a significant elevation in central adiposity with age. These findings may have important physiological and clinical implications for the role of regular endurance exercise in minimizing age-associated increases in body fatness-related chronic disease risk in healthy women.

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REFERENCES
