

Age-related decrease in resting energy expenditure in sedentary white women: effects of regional differences in lean and fat mass¹⁻³

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ABSTRACT

Background: Lean mass and resting energy expenditure (REE) decrease with age. However, it is unknown whether age-related changes in regional lean and fat mass are responsible for the age-related decrease in REE.

Objective: Our objective was to determine how regional lean and fat mass vary with age and whether age is independently related to REE after adjustment for regional fat and lean mass.

Design: The study was a cross-sectional evaluation of 58 white women aged 23–77 y. Regional and whole-body lean and fat mass were measured by dual-energy X-ray absorptiometry, subcutaneous abdominal tissue (SAT) and intraabdominal adipose tissue (IAF) by computed tomography, and REE by ventilated-canopy indirect calorimetry.

Results: Independent of other significant correlates, age was significantly and independently associated with greater IAF ($\beta = 0.49$) and less leg lean mass ($\beta = -0.35$). IAF ($r = -0.28$) and IAF:SAT ($r = -0.31$) correlated negatively with REE. REE was negatively associated with greater age ($\beta = -0.42$), independent of changes in lean and fat mass in different parts of the body. By contrast, trunk lean ($\beta = 0.27$) and leg fat ($\beta = 0.27$) mass were associated with greater REE independent of age and other body-composition variables.

Conclusions: These results suggest that trunk lean mass (presumably primarily organ tissue) is relatively resistant to age-related changes in body composition, whereas muscle mass, especially leg muscle, tends to be lost. These data also suggest that the age-related decreases in REE are not fully explained by changes in body composition. *Am J Clin Nutr* 2001;73:333–7.

KEY WORDS Aging, resting energy expenditure, body composition, elderly women, white women, dual-energy X-ray absorptiometry, fat mass, lean mass

INTRODUCTION

It is well established that fat-free mass (FFM) decreases and fat mass (FM) increases with age and that resting energy expenditure (REE) decreases with age. Because the distribution of FFM and FM in different parts of the body may change with age, it is of interest to determine whether the distributions of lean and fat mass change with age and whether changes in the distribution of lean and fat mass are related to the age-related decrease in REE.

Several studies in which various techniques were used to estimate metabolically active FFM suggested that the decline in REE is due primarily to reductions in FFM (1–4). On the other hand, other investigations suggested that REE is significantly lower in older than in younger adults even after adjustment for differences in FM and FFM (5–8). Not all FFM is equally metabolically active. At rest, organs such as brain, heart, liver, and kidney are estimated to have metabolic rates 15–25 times greater than that of muscle (9). We (10) and Svendsen et al (11) reported better relations between REE and trunk lean mass than between REE and limb lean mass. Using dual-energy X-ray absorptiometry (DXA) to measure both limb and trunk lean mass, Piers et al (12) reported significantly lower slopes of FFM-adjusted REE in older than in younger subjects. This suggests that the age-related decline in REE cannot be totally explained by changes in lean mass. It is known that fat mass makes a small but important contribution to metabolic rate (13), but it is not known whether the metabolic rate of fat tissue in different parts of the body varies. This could be important because older adults have a different distribution of fat mass than do younger adults (14–16). The proportion of fat distributed in the upper body and viscera is larger in older adults than in younger adults (15, 16). To our knowledge, no one has determined whether age-related changes in regional lean and fat mass distribution may be related to changes in REE.

Although it is well established that visceral fat increases more rapidly than does overall body fat with age, little is known about how the distribution of lean and fat mass in the arms and legs changes with age. There is some evidence to suggest that strength and muscle fiber size may be more affected in the legs than in the arms of older compared with younger adults (17–19). However, we are unaware of any studies that attempted to model age-related changes in fat and lean mass distribution in sedentary women varying widely in age. Therefore, the purpose of this study was 2-fold: 1) to determine how regional lean and fat mass

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vary with age and 2) to determine whether age is independently related to REE after adjustment for regional fat and lean mass. These results will assist in understanding age-related changes in body composition and REE.

SUBJECTS AND METHODS

Subjects

Fifty-eight white women aged 23–77 y served as subjects. All subjects were free of any metabolic disorders and medications that may affect REE. All women were nonsmokers, sedentary (defined as exercising less than once per week for the previous year), and weight stable (defined as remaining within 1% of body weight during the previous 4 wk). Twenty-six women were premenopausal and had normal menstrual cycles and 32 women had been postmenopausal for ≥ 2 y. For the premenopausal women, all measurements were made during the follicular phase of the menstrual cycle. Twenty-one of the postmenopausal women were receiving hormone replacement therapy and 11 were not. The breakdown of subjects by decade of age was: 20–29 y, 6; 30–39 y, 11; 40–49 y, 9; 50–59 y, 13; 60–69 y, 13; and ≥ 70 y, 6. All measurements were done between 0500 and 0800 after subjects had fasted for 12 h. Subjects had also refrained from use of caffeine and from exercise for ≥ 12 h. We chose 12-h abstinence from exercise to ensure that prior physical activity would not have an acute effect on REE while not changing any subject's normal lifestyle in a substantive way. The Institutional Review Board for Human Use of the University of Alabama at Birmingham approved the study and informed consent was obtained before subjects participated in the study, in compliance with the Department of Health and Human Services regulations for the protection of human research subjects.

Dual-energy X-ray absorptiometry

Bone mineral content and regional lean and fat mass (trunk, arm, and leg) were determined by DXA (DPX-L; Lunar Radiation Corp, Madison, WI). The scans were analyzed by using the adult software (version 1.33). The separation point between the arms and trunk was the glenohumeral joint, and the separation point between the legs and trunk was on an oblique angle through the neck of the femur. The DXA lean tissue measurement does not include estimates of bone mass or soft tissue mass, only soft lean tissue mass.

Computed tomography

Computed tomography scanning was done with a General Electric HiLight/HTD Advantage Scanner (GEC, Milwaukee). Radiographic factors were 120 kVp and 40 mA·s. The subjects were examined in the supine position with their arms stretched above their heads. It was found previously that visceral fat area from a single scan is highly correlated with overall visceral volume. Therefore, a single 5-mm scan for 2 s at the level of the 4th–5th lumbar vertebra was obtained (20). The attenuation range for adipose tissue was found to be -30 to -190 Hounsfield units (HU) by using procedures established by Kvist et al (21). The cross section of adipose tissue was determined by using a computerized fat tissue highlighting technique. The cross section between -30 and -190 HU in the respective areas was considered adipose tissue. Total adipose tissue was found by highlighting all adipose tissue in cross section. Intraabdominal

adipose tissue (IAF) was measured by encircling the muscle wall surrounding the abdominal cavity with a cursor. To obtain abdominal subcutaneous adipose tissue (SAT), IAF was subtracted from total adipose tissue. Both intra- and interobserver test-retest reliability were $r = 0.99$ with a CV $< 2\%$ based on the reevaluation of 20 scans.

Resting energy expenditure

After subjects rested for 15 min, REE was measured for 30 min with a computerized, open-circuit, indirect calorimetry system with a ventilated canopy (Delta Trac; Sensormedics, Yorba Linda, CA). Oxygen uptake and carbon dioxide production were measured continuously and values were averaged at 1-min intervals. Energy expenditure and respiratory quotient were calculated from the oxygen uptake and carbon dioxide production data by using the Weir equation (22).

Statistics

Simple zero-order correlations were used to analyze the relation between body-composition variables, REE, and age. To determine whether age was independently related to REE after adjustment for lean and fat mass distributions, multiple regression models were developed with REE as a dependent variable. To determine which fat and lean tissue depots changed with increasing age, multiple regression models were developed with age as the dependent variable. We used the regression model to show the relation between age and body-composition variables without regard to direction or causality. This approach results in a multiple regression model that identifies body-composition variables that are associated independently with age, suggesting a different pattern of change with age. Only variables that had significant zero-order Pearson product-moment correlations with REE or age and did not violate multicollinearity assumptions were considered for inclusion in the multiple regression analyses. For each model, multicollinearity violations were examined by using variance inflation factors. Variance inflation factors were < 3.0 for all models. α was set at $P < 0.05$ for all tests. All analyses were done by using SPSS (SPSS Inc, Chicago).

RESULTS

Means and SDs for all variables are given in **Table 1**. Menopausal status was significantly related to lean mass ($r = -0.40$, $P = 0.001$) but unrelated to REE after adjustment for age ($r = 0.09$, $P = 0.48$). Hormone status in the postmenopausal women was not significantly related to either lean mass ($r = -0.31$, $P = 0.08$) or REE ($r = -0.16$, $P = 0.35$). Inclusion of menopause and hormone replacement status in the multiple regression models designed to determine whether age was related to REE independently of lean and fat mass distribution did not change the model. In addition, neither menopause nor hormone replacement status entered either model. Therefore, menopause and hormone replacement status were not included in any subsequent analysis.

Simple zero-order correlations of age and REE with the various study measures are shown in **Table 2**. Age was positively associated with, percentage fat, IAF, and IAF:SAT. Age was negatively related to overall lean, arm lean, and leg lean mass. Overall, lean and fat mass were entered in the first multiple regression analysis modeling age (**Table 3**). Fat mass was included in this analysis



TABLE 1
Descriptive characteristics of the white women¹

Characteristic	Value
Age (y)	49.1 ± 14.1
BMI (kg/m ²)	23.7 ± 2.1
Weight (kg)	64.6 ± 6.8
Percentage body fat (%)	35.5 ± 5.2
Lean mass (kg)	40.6 ± 3.9
Fat mass (kg)	23.0 ± 5.3
Trunk lean mass (kg)	18.8 ± 1.9
Trunk fat mass (kg)	10.3 ± 3.0
Arm lean mass (kg)	4.1 ± 0.5
Arm fat mass (kg)	2.2 ± 0.7
Leg lean mass (kg)	12.7 ± 1.4
Leg fat mass (kg)	9.2 ± 2.1
IAF (cm ²)	92.1 ± 41.9
SAT (cm ²)	244.3 ± 73.9
IAF:SAT	0.39 ± 0.16
Trunk:limb fat	0.92 ± 0.22
REE (kJ/d)	5460 ± 766

¹ \bar{x} ± SD; *n* = 58. IAF, intraabdominal adipose tissue; SAT, subcutaneous abdominal adipose tissue; REE, resting energy expenditure.

because most existing data suggest that aging is associated with a reduction in lean mass and an increase in fat mass. Age was independently and inversely associated with lean mass but not with fat mass. The more complex model analysis of fat and lean tissue distribution included IAF, leg lean, arm lean, and arm fat mass. The analysis showed that age was significantly and independently associated with an increase in IAF and a decrease in leg lean mass.

As shown in Table 2, REE correlated negatively with age, whereas REE correlated positively with arm, leg, trunk, and overall lean mass. REE also correlated positively with leg fat mass but negatively with IAF and IAF:SAT. REE was not significantly related to any of the other fat-distribution variables. The first multiple regression model for estimating REE included lean and fat mass, along with age (Table 4). Although the zero-order correlation of 0.22 between fat mass and REE was not significant, it was included in this first model because fat mass has frequently been reported to be related to REE. Age, lean mass, and fat mass were all significant contributors to the REE model ($R^2 = 0.46$, SEE = 559 kJ/d), indicating that age is significantly related to REE even after adjustment for variations in lean and fat mass.

The second model included in Table 4 examined the relation between age and REE after adjustment for lean and fat mass in different parts of the body (ie, arm, leg, trunk, and IAF). All 6 variables included in this analysis (leg fat, trunk lean, leg lean, arm lean, IAF, and age) were significantly related to REE in the zero-order correlations. Although IAF:SAT was also significantly related to REE, it was not included to avoid multicollinearity problems with IAF. In this model, age was significantly related to REE, suggesting that there is an age-related reduction in REE separate from any changes in regional lean and fat distribution. The only other variables to enter the model as significant predictors of REE were trunk lean and leg fat mass (overall model $R^2 = 0.53$, SEE = 525 kJ/d).

DISCUSSION

Age was found to be independently related to REE after adjustment for body-composition variables. This finding is con-

sistent with the hypothesis that the well-established age-related decrease in REE is not caused entirely by changes in body composition. The age-related decrease in REE was present whether the adjusting variable was fat or lean mass and whether the tissue was located in the trunk, arm, leg, or viscera. Piers et al (12) showed that age is related to decreases in REE even after adjustment for differences in trunk and limb lean mass. Our findings extend their results by including both lean and fat tissue partitioning in the analysis of the relation of age and REE.

Compared with other studies, in the present study the correlation between lean mass and REE was relatively modest. We found a correlation of 0.47 whereas Poehlman et al (2) reported an R^2 of 0.72. The subjects in our study were homogeneous relative to lean mass; our subjects had a lean mass SD of 3.9 kg, whereas those of Poehlman et al had an FFM SD of 5 kg. We believe that the lower variance in lean mass in our sample probably contributed to the lower relation between lean mass and REE.

Our sample was relatively small and must be considered a limitation in this study. However, the subjects in this study were selected for their homogeneity of body weight. We wanted to minimize the variability in REE that was caused by differences in body size so that differences in age would be more easily detected. In addition, the sample size relative to the number of independent variables in all the regression models was well above the minimum of 5 to 1 recommended by Tabachnick and Fidell (23).

Our findings indicate that a greater proportion of the variability in REE was explained by the regression model that included lean and fat partitioning variables than by the model that included overall lean and fat mass variables ($R^2 = 0.53$ and 0.46, respectively). In the partitioning model, trunk lean and leg fat mass were the only body-composition variables that remained significantly related to REE after adjustment for age. The improvement in estimation of REE when trunk lean mass was included in the model was probably at least in part due to the high metabolic activity of trunk lean mass (presumably reflecting organ mass). Limb lean tissue was previously shown

TABLE 2
Pearson product-moment correlation coefficients of age and resting energy expenditure (REE) with various study measures in white women¹

Study measure	Age	REE
BMI	0.00	0.31 ²
Weight	-0.13	0.47 ³
Percentage body fat	0.26 ²	0.02
Lean mass	-0.42 ³	0.47 ³
Fat mass	0.12	0.22
Trunk lean mass	-0.22	0.48 ³
Trunk fat mass	0.19	0.10
Arm lean mass	-0.39 ³	0.40 ³
Arm fat mass	0.25 ²	0.09
Leg lean mass	-0.54 ³	0.56 ³
Leg fat mass	-0.08	0.38 ³
IAF	0.60 ³	-0.28 ²
SAT	0.21	0.02
IAF:SAT	0.51 ³	-0.31 ²
Trunk:limb fat	0.24	-0.25
REE	-0.57 ³	1.00

¹*n* = 58. IAF, intraabdominal adipose tissue; SAT, subcutaneous abdominal adipose tissue.

² $P < 0.05$.

³ $P < 0.01$.

TABLE 3
Multiple regression models identifying the best anthropometric predictors of age in white women¹

Model	Intercept	R ²	Slope	β	P
Model 1					
Constant	102.2	0.20	—	—	<0.01
Lean mass	—	—	-1.52	-0.43	<0.01
Fat mass	—	—	0.39	0.15	0.23
Model 2					
Constant	88.16	0.54	—	—	<0.01
IAF	—	—	0.16	0.49	<0.01
Leg lean mass	—	—	-3.38	-0.35	0.01
Arm lean mass	—	—	-3.50	-0.13	0.38
Arm fat mass	—	—	1.35	0.06	0.61

¹n = 58. Lean mass, fat mass, leg lean mass, arm lean mass, and arm fat mass are in kg; IAF (intraabdominal adipose tissue) is in cm².

to be primarily muscle, making up almost 80% of the skeletal muscle of the body (24) and is considered to be a good surrogate of muscle mass (12, 25). By process of elimination, trunk lean mass is considered a surrogate of metabolically active organ mass (12). Consistent with the contention that trunk lean mass is representative of organ mass and that limb lean mass is representative of muscle mass, stronger correlations have been reported between REE and trunk lean mass than between REE and limb lean mass (10, 11).

IAF was negatively related to REE. IAF:SAT was also inversely related to REE. These correlations were no longer significant after adjustment for age, suggesting that the relation of IAF to REE was only a surrogate of the well-documented age-related increase in IAF. One can only speculate as to whether the factors that mediate the age-related decrease in REE are the same factors that mediate the increase in visceral adipose tissue. These results strongly support the need for further research to examine the potential reasons for these changes.

It is more difficult to speculate why leg fat was independently associated with REE whereas arm and trunk fat were not. It is possible that multicollinearity with age may have decreased the relation of arm and trunk fat with REE. Arm fat was signifi-

cantly related to age; a large component of trunk fat (or IAF), was also significantly related to age. Because REE was lower and fat mass was higher in older subjects, the strong age effect on these 2 variables may have concealed the expected positive relation between trunk and arm fat and REE. Leg fat was not related to age, so multicollinearity with age would not have influenced the relation.

One variable that could potentially affect both body composition and REE is physical activity. It is well documented that physical activity can affect muscle mass, fat mass, and the distribution of fat mass (26–28). In addition, it is probable that physical activity affects REE, even after adjustment for FFM (29, 30). It is also well known that physical activity decreases with age (15, 31, 32). Because the age-related decrease in REE was independent of body composition, any physical-inactivity-mediated decline in REE would have to act in addition to the physical-activity-related decline in muscle. Available data suggest that exercise intensity needs to be high to have an effect on REE separate from body-composition changes (29, 33). All of the subjects in this study were sedentary and reported doing no high-intensity activity. Thus, it is probable that variations in physical activity in this group of sedentary women were not responsible for the independent age-related decline in REE. Further research is needed to examine the interrelations between physical activity, distribution of lean tissue, REE, and age.

Although few longitudinal studies are available, several cross-sectional studies suggest that skeletal muscle atrophy with age may be greater in the legs than in the arms (17–19). The significant independent relation found in this study between age and leg lean mass supports this finding. An age-induced preferential atrophy of type II muscle fiber area in the legs was suggested previously on the basis of the results of several cross-sectional studies (34–37). It is possible that this preferential atrophy or necrosis of leg type II muscle fiber may be related to physical activity. It is well established that the tonic type I muscle fibers will tend to be more active than the phasic type II muscle fibers during sedentary activities. Thus, age-related reductions in physical activity may result in larger age-related reductions in type II muscle fiber than in type I muscle fiber. However, the results of a study by Starling et al (38) suggest that changes in physical activity with age do not account for all of the age-related decline in appendicular skeletal mass.

The results of this cross-sectional study confirm previous reports that age-related changes in body composition are characterized by losses of lean mass and gains in adipose tissue. Through closer examination of the various tissue compartments, the findings also suggest that aging is associated with preferential loss of lean tissue from the legs and preferential gain of adipose tissue in the viscera. In contrast with the loss of limb lean mass, trunk lean mass does not appear to decline appreciably with age. This suggests that organ tissue is relatively resistant to age-related changes in body composition, whereas muscle mass, especially leg muscle, tends to be lost.


Our findings also agree with those of previous studies that indicate that aging is associated with a decrease in REE. Notably, however, this age-related decline in REE appears to be independent of changes in both lean and fat mass. The primary independent determinants of REE were trunk lean mass (presumably organ mass) and leg fat mass. Thus, it appears that aging has an independent effect on REE that is not explained by the age-related loss of leg muscle and gain in IAF. 

TABLE 4
Multiple regression models for estimation of resting energy expenditure in white women

Model	Intercept	R ²	Slope	β	P
Model 1					
Constant	950.8	0.46	—	—	<0.01
Age	—	—	-6.6	-0.50	<0.01
Fat mass	—	—	9.4	0.27	<0.01
Lean mass	—	—	11.3	0.24	0.03
Model 2					
Constant	764.7	0.53	—	—	<0.01
Age	—	—	-5.506	-0.42	<0.01
Leg fat mass	—	—	0.023	0.27	0.02
Trunk lean mass	—	—	0.027	0.27	0.03
Leg lean mass	—	—	0.017	0.13	0.44
Arm lean mass	—	—	-0.023	-0.07	0.64
IAF	—	—	-0.186	-0.04	0.74

¹Age is in y; fat mass, lean mass, leg fat mass, trunk lean mass, leg lean mass, and arm lean mass are in kg; and IAF (intraabdominal adipose tissue) is in cm².

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