Influence of distribution of lean body mass on resting metabolic rate after weight loss and weight regain: comparison of responses in white and black women 1–4

Nuala M Byrne, Roland L Weinsier, Gary R Hunter, Renee Desmond, Mindy A Patterson, Betty E Darnell, and Paul A Zuckerman

ABSTRACT

Background: Little is known about the effect of weight change on regional lean body mass (LBM) distribution or on racial differences in resting metabolic rate (RMR).

Objective: The study compared total and regional LBM patterns in white and black women after weight loss and regain and assessed the influence of regional LBM on variances in RMR.

Design: Eighteen white and 22 black women who did not differ in age, weight, and height were studied 3 times: in the overweight state, after weight reduction to the normal-weight state, and after 1 y without intervention. Total and regional lean and fat masses were assessed by dual-energy X-ray absorptiometry.

Results: White and black women did not differ significantly in mean (±SD) weight loss (13.4 ± 3.6 and 12.7 ± 3.2 kg, respectively) and regain (6.1 ± 5.5 and 6.4 ± 5.4 kg, respectively). Black subjects had significantly less trunk LBM and significantly more limb LBM at each time point (P < 0.05). In both races, weight regain was associated with significant increases in limb LBM (P < 0.05) but not in trunk LBM (P = 0.21). RMR, adjusted for total LBM and fat mass, was significantly higher in white women after weight loss (P < 0.01) and regain (P < 0.01). However, no racial difference was found when RMR was adjusted for LBM distribution.

Conclusions: In both races, trunk LBM decreased with weight loss and remained lower, despite significant weight regain, which potentially reflected decreased organ mass. Regional LBM distribution explained the racial difference in RMR. Am J Clin Nutr 2003;77:1368–73.

KEY WORDS Overweight, obesity, weight loss, body composition, resting metabolic rate, lean body mass, fat mass, regional distribution, African American women

INTRODUCTION

The prevalence of overweight and obesity is increasing (1, 2), and recidivism after weight loss is common (3, 4). The prevalence of obesity is greater in black women than in white women (5), and black women reputedly lose less weight with a range of treatment modalities (6–10). There remains considerable debate regarding the degree to which cultural, behavioral, physiologic, and metabolic factors are responsible for racial differences in weight gain, response to weight-loss treatment, and posttreatment recidivism. Some research suggests that obese black women have a lower resting metabolic rate (RMR) than do obese white women, even after adjustment for variation in body composition (11–13), and that weight loss results in a greater reduction in RMR (adjusted for body composition) in black women (10).

Racial differences in the distribution of fat and lean tissue have been found in both normal and overweight conditions. Black persons tend to have greater amounts of skeletal muscle (14, 15) and greater appendicular bone lengths (14–16) across all ages in adulthood than do white subjects. Gallagher et al (17) found that, although there was no racial difference in height, the black subjects in their study had greater leg length relative to their height than did the white subjects. Further, after adjustment for stature and body weight, age, sex, and ethnicity are all significant independent determinants of appendicular skeletal muscle mass (17). These racial differences may have some effect on energy expenditure. Given the differences in the energetics of the different components of lean body mass (LBM; 18–20), variation in the proportion of organ tissue to skeletal muscle tissue may explain some of the residual variability in RMR beyond that explained by total LBM (21, 22).

In a sample of 40 normal-weight white adults, Sparti et al (23) found that regression models based on organ size did not improve the estimation of RMR beyond that obtained with the use of the traditional model based on LBM and fat body mass. In contrast, we have recently shown cross-sectionally that differences in sleeping energy expenditure and RMR between black and white women may be mediated by proportionately lower trunk LBM (and thus lower organ mass) in black women (24). However, little is known about the effect of weight loss and weight regain on...
changes in regional lean mass and fat mass distributions in different races or about whether regional lean tissue distribution may explain race differences in RMR.

Dual-energy X-ray absorptiometry (DXA) provides the opportunity to study both total and regional fat and lean tissue in vivo (17). Earlier research (25–29) supports the validity of DXA estimates of regional lean tissue. With the use of DXA, the mass of skeletal muscle may be approximated by measurement of the lean mass of the extremities (17). The purposes of the current study were to compare total and regional lean mass and fat mass patterns in white and black women in 3 weight states (overweight, normal-weight, and at 1-y follow-up) with the use of DXA and, if racial differences were found, to assess the degree to which regional lean tissue mass explains variance in RMR in different weight states.

SUBJECTS AND METHODS

Study subjects

Subjects were 18 white and 22 black premenopausal women aged 20–46 y who had a baseline body mass index (BMI; in kg/m²) of 27–30 (chosen to increase the likelihood that subjects could attain a normal weight in a reasonable time frame) and a family history of obesity (BMI > 27) in at least one first-degree relative. Classification of subjects as black or white was based on self-reporting. Normal glucose tolerance was documented by measurement of fasting blood glucose concentrations and 2-h postprandial blood glucose concentrations after an oral glucose load. Subjects were nonsmokers, were sedentary, and had normal menstrual cycles. The study protocol was approved by the Institutional Review Board of the University of Alabama at Birmingham. Written informed consent was obtained from all subjects before study participation, in compliance with Department of Health and Human Services Regulations for Protection of Human Research Subjects. The cohort studied features a number of subjects [15 white and 20 black women (30); 14 white and 19 black women (31)] who were included in data previously reported from our laboratory [the General Clinical Research Center (GCRC) at the University of Alabama at Birmingham]; however, the outcome variables in these previous studies were different from those in the current investigation.

Study design

Subjects were evaluated at 3 time points: in the overweight state, in the normal-weight state, and after 1-y follow-up. Study variables were assessed under weight-stable, diet-controlled conditions through the GCRC. Before each evaluation, subjects were monitored twice a week until subjects lost >10 kg and then admitted to the GCRC for 4 d, during the follicular phase of the menstrual cycle. After their discharge, the GCRC prepared all meals for weight reduction, providing 3350 kJ/d (800 kcal/d) and including frozen entrées twice daily (Stouffer’s Lean Cuisine; Nestlé Food Co, Solon, OH). Dietary adherence and body weight were monitored twice a week until subjects lost >10 kg and reached a normal weight, defined as a BMI < 25. Although they were sedentary, no attempt was made to alter their physical activity patterns. On reaching a normal BMI, subjects repeated the protocol of energy balance for 4 wk and GCRC admission for 4 d. After their discharge in the normal-weight state, no intervention was provided, and the subjects were contacted <10 mo later to schedule a follow-up evaluation according to the same protocol of weight maintenance for 4 wk before GCRC admission.

Study variables

Measurements of body height (stretch stature) to the nearest 0.1 cm with the use of a stadiometer and of body weight to the nearest 5 g recorded on a digital scale were taken when subjects were in a fasted state and immediately after they voided in the morning. Whole-body and regional (trunk, arm, and leg) lean and fat tissue were determined with the use of DXA (DPX-L; Lunar Radiation Corp, Madison, WI). The scans were analyzed with the use of ADULT software, version 1.33 (Lunar Radiation Corp). The calculation of appendicular lean and fat mass was made according to the approach described by Heymsfield et al (25). With the use of specific anatomic landmarks, the legs and arms are isolated on the skeletal X-ray planogram (anterior view). The arm encompasses all soft tissue extending from the center of the arm socket to the phalange tips, and contact with the ribs, pelvis, or greater trochanter is avoided. The leg consists of all soft tissue extending from an angled line drawn through the femoral neck to the phalange tips. The system software provides the total mass, ratio of soft tissue attenuations, and bone mineral mass for the isolated regions. The ratio of soft tissue attenuation for each region was used to divide bone mineral–free tissue of the extremities into fat and lean components. Limb fat and lean tissue were calculated from summed arm and leg fat and lean tissues, respectively.

Subjects spent 23 h in a whole-room respiration calorimeter (3.38-m long, 2.11-m wide, and 2.58-m high) for measurement of total energy expenditure and RMR. The design characteristics and calibration of the calorimeter were described previously (32). Oxygen consumption and carbon dioxide production were continuously measured with the use of a magnetopneumatic differential oxygen analyzer (Magnos 4G; Hartmann & Braun, Frankfurt, Germany) and a nondispersive infrared industrial photometer differential carbon dioxide analyzer (Uras 3G, Hartmann & Braun. The calorimeter was calibrated before each subject entered the chamber. The zero calibration was carried out simultaneously for both analyzers. The full scale was set for 0–1% for the carbon dioxide analyzer and for 0–2% for the oxygen analyzer. Each subject entered the calorimeter at 0800. Although metabolic data were collected throughout the 23-h stay, only RMR data are reported here. Each subject was awakened at 0630 the next morning in the calorimeter. RMR was then measured for 30 min before the subject left the calorimeter at ~0700. Energy expenditure was calculated by the Weir equation (33). The RMR data were extrapolated over 24 h and expressed as kJ/d.

Statistical analysis

Statistical analyses were performed with the use of SPSS software, version 10.0 (SPSS Inc, Chicago) and SAS software, version 8.0 (SAS Institute, Inc, Cary, NC). Descriptive statistics for the outcome variables were calculated for the total sample and for both racial groups at each study state. Two-way repeated-measures analysis of variance was performed to determine whether there were any statistically significant differences in outcome variables between the races across the 3 study phases. Post hoc tests were run to examine the separate effects of weight loss on the mean values of body composition in each race, with the use of Bonferroni
corrections for additive alphas. To determine whether RMR, adjusted for body composition variables, was altered with weight loss and weight regain and whether racial differences existed with altered weight states, repeated-measures analysis of covariance (ANCOVA) was performed. A 2 × 2 (time × race) ANCOVA was performed to determine whether there were any statistically significant differences in outcome variables (RMR; raw and adjusted for body composition variables) between the races, between subjects in the overweight and normal-weight states, and between subjects in the normal-weight state and those at 1-y follow-up. Two analyses were required to deal with lack of linearity for change in the adjusting variables (LBM and fat mass) between the 3 time points. Mean values for the normal-weight state are reported in Table 1. Bonferroni corrections were made to correct for additive alphas. Significance was set at P < 0.05 for all tests. Although a 3 × 2 (time × race) repeated-measures ANCOVA would allow analysis of all 3 time points in one analysis without the use of Bonferroni corrections, a fundamental flaw exists in repeated-measures ANCOVA when ≥3 time points are being examined and the covariate or covariates do not change linearly across time. This flaw occurs because repeated-measures ANCOVA adjustments on the dependent variable mean are made at each time point on the basis of a linear regression of the different covariates across time points. No problem exists with the adjustments when only 2 time points exist, when the covariates do not change across time, or when they change in a linear manner. However, repeated-measures ANCOVA is not capable of appropriately adjusting ≥3 time points when the adjusting variable follows a nonlinear pattern across time points. The covariates in the analysis of RMR (LBM and fat mass) did not change linearly across time in this study (ie, fat mass starts at 31.7 kg, drops to 20.5 kg, and then rises to 27 kg; LBM follows the same pattern). Therefore, two 2 × 2 repeated-measures ANCOVAs with Bonferroni corrections for additive alpha were required for the repeated-measures ANCOVA of RMR.

### RESULTS

At baseline (overweight state), there were no significant differences between the white and black women in mean (± SEM) body weight (78.7 ± 5.3 and 78.0 ± 9.0 kg, respectively), BMI (29.1 ± 1.6 and 28.8 ± 1.7, respectively), or percentage body fat (44.7 ± 3.4 and 43.5 ± 5.7, respectively). Furthermore, the white and black women did not differ significantly in age (37.4 ± 5.9 and 35.4 ± 6.0 y, respectively). The duration of weight-loss treatment averaged 0.42 ± 0.11 y and 0.48 ± 0.26 y in the white and black women, respectively (P = 0.44). The magnitude of weight loss from baseline did not differ significantly between the races, averaging 13.4 ± 3.6 kg in the white women and 12.7 ± 3.2 kg in the black women (17% and 16%, respectively). The duration of follow-up after assessment in the normal-weight state averaged 0.99 ± 0.48 y and 0.96 ± 0.23 y in the white and black women, respectively (P = 0.50). Weight regain averaged 6.1 ± 5.5 kg in the white women and 6.4 ± 5.4 kg in the black women (9% and 10%, respectively). Body weight, percentage body fat, LBM, and fat mass changed significantly (all P < 0.001), and, at each of the 3 measurement time points, the white and black women did not differ significantly in these variables (Table 2).

Whereas the races did not differ in trunk or limb fat mass, there were significant racial differences in the regional distribution of LBM. Trunk LBM was significantly lower in blacks than in whites, as shown in Figure 1. In contrast, limb LBM was significantly greater in blacks than in whites. With weight loss, trunk and limb LBM and fat mass decreased significantly in both groups (Table 2, Figure 1). When the data for black and white women were evaluated collectively, total fat mass but not total LBM increased significantly from the normal-weight state to the 1-y follow-up. Differences were also noted for regional tissue distributions during weight regain. Whereas trunk and limb fat mass and limb LBM increased significantly from the normal-weight state to the 1-y follow-up, trunk LBM remained lower despite the average body weight regain of 6.2 kg.

Absolute RMR values decreased significantly as a function of weight change (Table 1). However, the influence of weight change on RMR was not significant after adjustment for total LBM and fat mass or after adjustment for regional LBM. Racial differences in absolute RMR were not statistically significant (P = 0.05), but differences in RMR were evident when adjustments were made for total LBM and fat mass (P = 0.01): white women had a significantly higher adjusted RMR. However, this racial difference in RMR was no longer present (P = 0.94) after adjustment for regional LBM and fat mass.

### DISCUSSION

As we (24) and others (14, 15, 17) found previously, we found in the present study that, matched for height and weight, premenopausal black women have more limb LBM and less trunk LBM than do premenopausal white women. To our knowledge, this is the first study to test the effects of weight loss and regain on the distribution of LBM in premenopausal black and white women. Trunk and limb LBM decreased proportionately in black women.
TABLE 2
Body composition of 40 women (18 white and 22 black) measured in the overweight state (baseline), after weight reduction to a normal body weight, and at follow-up after an average of 1 y without intervention.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Overweight state</th>
<th>Normal-weight state</th>
<th>At follow-up after 1 y</th>
<th>Weight change</th>
<th>Race</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>78.3 ± 7.5a</td>
<td>65.4 ± 6.4b</td>
<td>71.6 ± 8.3c</td>
<td>&lt;0.001</td>
<td>0.94</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>29.0 ± 1.7b</td>
<td>23.9 ± 1.0b</td>
<td>26.3 ± 2.5c</td>
<td>&lt;0.001</td>
<td>0.79</td>
</tr>
<tr>
<td>Percentage body fat</td>
<td>42.6 ± 3.5a</td>
<td>33.1 ± 4.6b</td>
<td>39.0 ± 5.3c</td>
<td>&lt;0.001</td>
<td>0.70</td>
</tr>
<tr>
<td>(soft tissue only)</td>
<td>44.1 ± 3.6b</td>
<td>34.4 ± 4.8b</td>
<td>37.2 ± 6.5c</td>
<td>&lt;0.001</td>
<td>0.27</td>
</tr>
<tr>
<td>Total LBM (kg)</td>
<td>40.1 ± 4.0b</td>
<td>38.8 ± 4.0b</td>
<td>39.2 ± 4.3c</td>
<td>&lt;0.001</td>
<td>0.88</td>
</tr>
<tr>
<td>Total FM (kg)</td>
<td>31.7 ± 4.4b</td>
<td>20.5 ± 4.0b</td>
<td>27.0 ± 5.9f</td>
<td>&lt;0.001</td>
<td>0.74</td>
</tr>
<tr>
<td>Trunk LBM (kg)</td>
<td>19.4 ± 2.2a</td>
<td>18.9 ± 2.3b</td>
<td>18.7 ± 2.4c</td>
<td>&lt;0.001</td>
<td>&lt;0.04</td>
</tr>
<tr>
<td>Trunk FM (kg)</td>
<td>14.4 ± 2.0a</td>
<td>9.0 ± 2.3b</td>
<td>11.8 ± 3.1c</td>
<td>&lt;0.001</td>
<td>0.14</td>
</tr>
<tr>
<td>Limb LBM (kg)</td>
<td>19.3 ± 2.4a</td>
<td>18.5 ± 2.2b</td>
<td>19.0 ± 2.4c</td>
<td>&lt;0.001</td>
<td>0.02</td>
</tr>
<tr>
<td>Limb FM (kg)</td>
<td>17.3 ± 3.1a</td>
<td>11.4 ± 2.6b</td>
<td>15.2 ± 3.5c</td>
<td>&lt;0.001</td>
<td>0.40</td>
</tr>
</tbody>
</table>

1x ± SD. LBM, lean body mass; FM, fat mass. Values in the same row with different superscript letters are significantly different, P < 0.05 (post hoc tests).
2Repeated-measures ANOVA examining independent effects of weight change, race, and their interaction. No race-by-weight change interactions were significant.

and white women with weight loss. However, with weight regain 1 y after the achievement of normal-weight status, the women had regained limb LBM, whereas trunk LBM remained reduced. Thus, an interesting feature of this study was that, despite the absolute differences between the races in the distribution of regional body composition, the black and white women had the same temporal pattern in regional tissue changes during weight loss and weight regain. Further, organ mass is contained within the trunk LBM; by contrast, limb LBM is primarily muscle and represents <75% of total skeletal muscle mass (27). Consequently, the results of the current study suggest that, for both races, a delay may exist in the regain of metabolically active organ mass during the first year of weight regain after weight loss.

LBM is known to be a function of stature and body weight (25, 34). Because the average heights of the black and white women in the current study did not differ by >1 cm and their average body weights were within 1 kg at each time point, it is not surprising that no racial difference was found in total LBM at any measurement point. However, racial differences were found in LBM distribution: trunk LBM was significantly lower and limb LBM was significantly higher in the black women. Previous research noted that, compared with white subjects, black subjects have greater amounts of skeletal muscle (14, 15) and greater appendicular bone lengths (14–16) at any given age across adulthood. Gallagher et al (17) compared black and white adults and found that, whereas there was no racial difference in height, the black subjects had greater leg length relative to their height than did the white subjects. Using the same measurement technique adopted in the current study, Gallagher et al (17) found that, after adjustment for stature and body weight, ethnicity independently determined a person’s appendicular skeletal muscle mass and that the black women had more limb skeletal tissue than did the white women. In a study that used DXA to measure racial differences in body composition, Aloia et al (28) found that, after adjustment for height, weight, and age, the black women had significantly greater skeletal muscle mass than did the white women. It was further

FIGURE 1. Mean (± SEM) trunk and limb lean mass among 18 white (○) and 22 black (●) women measured in the overweight state (baseline), after weight reduction to the normal-weight state, and after an average of 1 y without intervention.
shown that muscle mass as a proportion of total lean tissue was significantly greater in the black women than in the white women. However, the subjects from these studies were of normal weight, and the racial groups differed significantly in age and weight. Data from the current study extend the findings of these previous studies by showing that black and white women who do not differ in stature, weight, and age have significant differences in limb LBM as well as trunk LBM and that these racial differences appear to be inherent and persistent, because they exist throughout the overweight, normal-weight, and weight-regain states.

It has been shown (10, 35, 36) that RMR is lower in blacks than in whites after adjustment for total LBM and fat mass. Consequently, the secondary aim of this study was to investigate what role a racial difference in the regional LBM distribution in weight-matched women might have in explaining possible differences in RMR. Basal, sleeping, and resting metabolic rates are highly correlated with body weight in general and with LBM in particular, because its metabolic rate is higher than that of fat tissue (37). Consequently, the results of the current study have implications for analyses of metabolic rate, especially in comparisons of racial groups. In the current study, the black and white women did not differ in total LBM. However, the lower trunk LBM and higher limb LBM in the black women suggest that they have less organ tissue and more skeletal muscle tissue than do the white women. Organ tissue is more metabolically active than is skeletal muscle tissue during resting conditions, which explains a greater proportion of the variances in RMR (20). These findings suggest that, even when RMR is adjusted for differences in LBM, previously observed racial differences in metabolic rate may still exist because of the divergence in the ratio of organ to skeletal tissue. Research by Sparti et al (23) in 40 normal-weight adults did not support the hypothesis that the composition of the fat-free mass was the main determinant of RMR. However, we have shown cross-sectionally that differences in sleeping energy expenditure and RMR between black and white women may be mediated by proportionately lower trunk LBM (and thus lower organ mass) in the black women (24). This is the first study to test this hypothesis longitudinally.

The data from the current study concur with the findings of Foster et al (10, 11) that racial differences in RMR are evident in weight-matched white and black women even after adjustment for total LBM. However, the current study shows longitudinally for the first time that these racial differences in RMR during weight loss and regain of an average of 19 kg fat mass, 20% fat-free mass) and the regain of an average of 19 kg fat mass during a weight cycle. Wadden et al (38) studied changes in LBM through a cycle of weight loss and total weight regain. There was no significant increase in RMR following weight regain, despite the fact that body weight and body fat mass had returned. Furthermore, although racial differences were seen during weight loss and weight regain when RMR was adjusted for total LBM and fat mass, these differences were no longer evident after adjustment for regional LBM distribution. Consequently, these results show that, in comparing energy expenditure between races, adjustment for differences in distribution of LBM may have to be considered.

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