Activity energy expenditure and adiposity among black adults in Nigeria and the United States

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ABSTRACT

**Background:** The prevalence of obesity is higher among populations in industrialized than in developing countries.

**Objective:** We sought to compare the relations of activity energy expenditure (AEE) with adiposity and weight change in 2 black populations with different levels of obesity.

**Design:** Total daily energy expenditure (TDEE) and resting energy expenditure (REE) were measured and AEE was calculated in 58 Nigerian and 34 US black women and men. Weight was remeasured after ≥1 y in a subset of participants. AEE adjusted for body size and TDEE adjusted for REE were calculated with the use of the residual regression method. The cross-sectional relations between percentage body fat and activity were modeled by using regression analysis, and longitudinal relations between weight change and adjusted energy expenditure variables were calculated.

**Results:** Women and men from the United States weighed more, had more body fat, and had higher levels of TDEE, REE, and AEE than did those from Nigeria. Cross-sectionally, AEE was negatively associated with adiposity after adjustment for body size and age (P < 0.001), regardless of site. Between 60% and 80% of the variance in adiposity was explained by AEE or TDEE. REE, AEE, and TDEE adjusted for body size and age were negatively correlated with weight change among Nigerian women but not men.

**Conclusions:** The significant difference observed in mean adiposity between Nigerians and US blacks was not explained by differences in AEE. However, a low AEE was an important determinant of high percentages of body fat in black adults and was associated with increased weight gain in Nigerian women.


**KEY WORDS** Obesity, energy expenditure, developing countries, Nigeria, blacks, African Americans, United States

INTRODUCTION

The prevalences of overweight and obesity have increased dramatically over the past few decades in most industrialized countries (1, 2). During the same time period, many developing countries have undergone an economic transition from societies characterized by subsistence agriculture to increased urbanization and industrialization. This transition is typically accompanied by changes in food supply, type of physical activity, level of physical activity, sanitation, and access to health care (3, 4), followed by a relative increase in obesity and its attendant chronic diseases (5).

Obesity is the result of an imbalance between energy intake and energy expenditure. Research into mechanisms has been hampered by the difficulty in making direct measurement of these quantities. Cross-sectional studies have often, though not consistently, documented an inverse relation between physical activity expenditure and adiposity (6–10). Longitudinal studies that examined the relation between total or activity energy expenditure (AEE) and obesity have also yielded inconsistent results (11–13). Until recently, there had been no studies documenting trends in energy expenditure in a population that had undergone a major economic or nutritional transition. Migration studies offer the best opportunity to study the relations between environmental factors (eg, energy expenditure) and health outcomes as populations move from one environment to another (14, 15). The number of such large-scale population movements is relatively small, and it is difficult to track individuals during the actual course of these migrations; however, contrasts can be made between related populations living in different environments. Esparza et al (16), for example, recently reported different levels of total energy expenditure and physical activity among 2 separate populations of Pima Indians. The Pimas living a traditional lifestyle in northwest Mexico had both higher energy expenditures and lower levels of adiposity than did the Pima Indians living in Arizona.

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2 Supported in part by grants from the National Institutes of Health (HL 45508, DK30031, and DK26678) and by an endowment from the William G Potts Estate, Loyola University Stritch School of Medicine.

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The African diaspora, a consequence of the forced migration of Africans to the Western Hemisphere between the 16th and 19th centuries, provides another possibility to examine the influence of environment on obesity prevalence. Similarly to the Pima Indians of Arizona and northwest Mexico, the prevalences of obesity and the associated chronic diseases are much higher among populations of West African origin currently living in the United States than in those residing in West Africa (17–19). For black populations living in the Caribbean and the United Kingdom, obesity and its sequelae are on the rise, particularly among women, with rates intermediate between those in Africa and those in the United States (20–23).

In this study we directly measured energy expenditure and body composition in Nigerians and African Americans to compare populations that share genetic ancestry yet live under different social and economic conditions. The study of populations with very different mean levels of adiposity provides a much broader range of exposure across which to examine the relations between body composition and components of energy expenditure than might be possible in any one cultural setting.

SUBJECTS AND METHODS

Recruitment of participants

Ongoing community-based studies of hypertension provided the sampling frame for participants in Maywood, IL, and in the rural community of Igbo-Ora and the city of Ibadan, both in Nigeria. The parent study, the International Collaborative Study on Hypertension, has recruited >20000 individuals in West Africa, the Caribbean, and the United States in the past 10 y for cross-sectional surveys and longitudinal studies of hypertension (20). Recruitment of participants for the parent study was based on the probability proportional to size sampling method (24). In brief, after identification of appropriate geographic subunits (ie, housing compounds in Nigeria and city blocks in the United states), a random sample was generated, proportional to the size of the subunit, and all eligible participants were approached to participate in the study.

Participants between the ages of 18 and 55 y were randomly selected from the parent study enrollees. All participants were free of significant medical illnesses [including thyroid disorders, coronary heart disease, osteoarthritis, and acute infection (eg, malaria)] and were not engaged in any weight-loss practices. All participants from both the urban and rural communities of Nigeria were of Yoruba ethnicity, whereas in the United States the participants were self-identified as being of African ancestry.

The study protocol was approved by the Institutional Review Boards of Loyola University Stritch School of Medicine (Maywood, IL) and the University College Hospital, Ibadan, Nigeria. Written, informed consent was obtained from all participants; in Nigeria, the informed consent document was translated into and presented in Yoruba.

Energy expenditure measurements

Total daily energy expenditure

The doubly labeled water (DLW) method was described in detail elsewhere (25). The DLW measurement period lasted 14 d for the US participants but only 10 d for the Nigerian participants because of uncertainty concerning the rate of water turnover in the tropics. Deuterium and 18O elimination rates were calculated by the 2-point method with the use of isotopic enrichment relative to baseline and the time difference between the third postdose and the final urine samples (26). The mean (±SD) ratio of deuterium to 18O dilution spaces for both sites combined was 1.035 ± 0.017, which agrees well with previously published data (27). The food quotient used for determining total daily energy expenditure (TDEE) (28) was based on site-specific dietary analyses (29; E Choboso, unpublished observations, 1994) and varied by site: 0.90 in Nigeria and 0.85 in the United States.

Resting energy expenditure

All measurements of resting energy expenditure (REE) were made by using the same protocol and indirect calorimetry system in both sites, ie, the DeltaTrac II metabolic monitor (SensorMedics, Anaheim, CA). All REE measurements were made in health clinics on an outpatient basis after participants had fasted from 2200 the previous evening. The measurement rooms were thermoneutral relative to the respective environments (ie, an ambient temperatures of 28°C in Nigeria and of 23°C in the United States); both sites were at approximately sea level. In all participants, measured REE was stable (<10% variability) for 20–30 min. REE was calculated from inspired oxygen and expired carbon dioxide according to the modified Weir equation with the use of data from the last 20–30 min of the measurement period and was expressed as MJ/d (30).

 METHanol burn tests showed the instrument to be accurate to within ±2%. A total of 52 duplicate measurements were made on participants and staff on separate days up to 18 mo apart with a resulting CV of 3.3%. The instrument was calibrated for barometric pressure in both sites. Three of the Nigerian participants were not available for measurement of REE; therefore, their values were predicted from the Cunningham equation with the use of fat-free mass (FFM) derived from isotope dilution (31); the correlation between measured and predicted REE was high in the other Nigerian participants (r = 0.96).

Activity energy expenditure

AEE (in MJ/d) was calculated as

\[
AEE = TDEE - REE - (0.1 \times TDEE)
\]

The term "0.1 × TDEE" represents the estimated 10% of TDEE expended as the thermic effect of food (32). The physical activity level (PAL) was calculated as the ratio of TDEE to REE (33).

Body composition and anthropometry

Body composition was measured by using the isotope-dilution method and was carried out concurrently with the DLW procedure. The isotope-dilution method is based on the dilution principle and was described in detail elsewhere (34). Total body water was calculated for each isotope and the 2 values were averaged. FFM was calculated by dividing the average total body water by a hydration constant (0.73) (35). Fat mass (FM) was calculated as the difference between body weight and FFM.

Body weight was measured to the nearest 0.1 kg with a calibrated portable electronic digital scale while participants were shoeless and wearing light clothing. Height was measured against a vertical wall with a wooden headboard and was recorded to the nearest 0.1 cm while the patients were shoeless. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m²). The participants returned to each clinic after ≥1 y for follow-up measurement of weight. Weight change was calculated as the differ-
TDEE adjusted for REE. All statistical analyses were carried out using two multivariate linear regression models. Within-sex comparisons of mean characteristics were also made between the 2 sites by using two-way analysis of variance (ANOVA). Sex-specific analyses were conducted because we strongly suspected that weight changes would be significantly different between the men and women at follow-up.

### Statistical methods

Statistical analyses were undertaken to define the relations between adiposity, expressed as percentage body fat, and components of energy expenditure among black adults from 2 sites. No one statistical method for the expression and comparison of AEE between populations is universally accepted; therefore, AEE was adjusted for body size in 3 ways: 1) AEE divided by body weight (in kJ·kg body wt\(^{-1}\)·d\(^{-1}\)\(^{(36, 37)}\), 2) AEE adjusted for body weight with the use of the residuals from the regression of AEE on weight (MJ/d) \(^{(38)}\), and 3) TDEE adjusted for REE with the use of the residual regression method \(^{(8, 16)}\). Mean values for these adjusted variables were compared between populations. Within-sex comparisons of mean characteristics were also made between the 2 sites by using two-way analysis of variance with a test for interaction.

The cross-sectional relations between adiposity and components of the energy budget were determined by using two multivariate regression models. Percentage body fat was the dependent variable in both of the models tested. In model 1, AEE and weight were the primary independent covariates, with dummy variables included for sex and site. In model 2, the independent covariates were TDEE and REE. We also tested for an interaction between sex and TDEE or AEE in each model. Pearson correlation coefficients were calculated to assess the strength of association between weight change and AEE adjusted for body weight or TDEE adjusted for REE. All statistical analyses were carried out with the use of STATA for WINDOWS (version 6.0; Stata, College Station, TX) \(^{(39)}\).

### RESULTS

Participants included 58 adults from Nigeria (28 women and 30 men) and 34 from the United States (22 women and 12 men) (Table 1). Compared with the US women, the Nigerian women weighed significantly less and had a significantly mean lower BMI, FFM, FM, and percentage body fat. This pattern was consistent among the men; the Nigerians had a significantly lower mean height, weight, BMI, FFM, and FM. Percentage body fat did not differ significantly between the Nigerian and US men.

As expected, mean unadjusted REE, AEE, and TDEE were significantly higher in the United States than in the Nigerian participants of both sexes (Table 1) because the US participants had larger body sizes than did the Nigerians. PALs did not differ significantly between sites in either the women or the men. After adjustment for body size and age, all of the differences in unadjusted mean energy expenditure variables observed between the 2 sites disappeared (Table 2).

Cross-sectionally, AEE adjusted for body weight and age was a significant negative predictor of adiposity \((P < 0.001)\) (Table 3). A regression model including age, sex, weight, and AEE explained 77% of the variance observed in percentage body fat. A similar model, after controlling for the additional effect of REE, explained 66% of the variance observed with TDEE, which was also a negative determinant of adiposity \((P < 0.05)\) (Table 4).

The cross-sectional association between AEE divided by body weight and percentage body fat in the men and women from both sites is illustrated in Figure 1. In each of the models, sex was a significant predictor of adiposity.
was negatively correlated with AEE divided by body weight in the women. Because of the small sample size, the only significant association among the women was that weight change and REE adjusted for FFM and age. Among the Nigerian men, however, no significant associations were observed between the energy expenditure variables and weight change. We acknowledge that statistical testing did not show a significant sex \( \times \) site interaction; therefore, the findings related to weight change in the subgroup of Nigerian women may have been due to chance. Nonetheless, a strong prior expectation, based on knowledge of population effects, suggests that the pattern of weight change in women may be different from that in men.

### DISCUSSION

A strong inverse cross-sectional relation between AEE adjusted for body weight and adiposity was observed between 2 populations of West African origin. Weaker but consistently inverse associations were observed between weight change per year and adjusted REE, AEE, and TDEE among women but not men in Nigeria. Although mean differences in body size and adiposity between the 2 population samples were not explained by differences in AEE, these data support the idea that low levels of physical activity are important in explaining the high levels of body fat in both Nigeria and the United States.

The lack of significant differences in energy expenditure measures between the 2 sites was surprising because the socioeconomic environment and types of physical activity varied greatly between the 2 populations in these sites. Although the Nigerian sample represented both urban and rural populations, none of the measured variables were significantly different between the urban tradespeople and the rural agriculturalists. Both groups have much less access to mechanization than do persons in the United States; therefore, it was expected that AEE, however defined, would be higher in Nigeria. However, this outcome was not observed. In fact, no significant differences between the Nigerian and US cohorts were observed for any of the various energy expenditure variables measured.

### TABLE 3

Regression coefficients for model describing the relation between percentage body fat and activity energy expenditure (AEE) adjusted for body size and age

<table>
<thead>
<tr>
<th>Covariate</th>
<th>( \beta ) Coefficient</th>
<th>SE</th>
<th>95% CI</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEE (MJ/d)</td>
<td>-1.30</td>
<td>0.39</td>
<td>-2.08, -0.52</td>
<td>0.001</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>0.31</td>
<td>0.04</td>
<td>0.22, 0.39</td>
<td>0.001</td>
</tr>
<tr>
<td>Age (y)</td>
<td>0.22</td>
<td>0.06</td>
<td>0.09, 0.35</td>
<td>0.001</td>
</tr>
<tr>
<td>Sex</td>
<td>14.54</td>
<td>1.24</td>
<td>12.07, 17.01</td>
<td>0.001</td>
</tr>
<tr>
<td>Site</td>
<td>3.41</td>
<td>1.90</td>
<td>-0.37, 7.20</td>
<td>0.11</td>
</tr>
<tr>
<td>Intercept</td>
<td>7.95</td>
<td>3.19</td>
<td>-14.30, -1.61</td>
<td>0.02</td>
</tr>
</tbody>
</table>

*Model: \% Fat = \( \alpha + \beta_1 \times \text{AEE} + \beta_2 \times \text{weight} + \beta_3 \times \text{age} + \beta_4 \times \text{sex} + \beta_5 \times \text{site} \), where for sex, \( 0 = \text{male} \) and \( 1 = \text{female} \) and site was defined so that Nigeria was the reference group. \( r^2 = 0.77 \), root mean squared error = 5.6%.

### TABLE 4

Regression coefficients for model describing the relation between percentage body fat and total daily energy expenditure (TDEE) adjusted for resting energy expenditure (REE) and age

<table>
<thead>
<tr>
<th>Covariate</th>
<th>( \beta ) Coefficient</th>
<th>SE</th>
<th>95% CI</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDEE (MJ/d)</td>
<td>-0.83</td>
<td>0.43</td>
<td>-1.67, 0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>REE (MJ/d)</td>
<td>3.77</td>
<td>1.02</td>
<td>1.73, 5.81</td>
<td>0.001</td>
</tr>
<tr>
<td>Age (y)</td>
<td>0.34</td>
<td>0.07</td>
<td>0.19, 0.49</td>
<td>0.001</td>
</tr>
<tr>
<td>Sex</td>
<td>16.0</td>
<td>1.79</td>
<td>12.4, 19.5</td>
<td>0.001</td>
</tr>
<tr>
<td>Site</td>
<td>9.53</td>
<td>2.00</td>
<td>5.56, 13.51</td>
<td>0.001</td>
</tr>
<tr>
<td>Intercept</td>
<td>-12.85</td>
<td>5.75</td>
<td>-24.27, -1.43</td>
<td>0.05</td>
</tr>
</tbody>
</table>

*Model: \% Fat = \( \alpha + \beta_1 \times \text{TDEE} + \beta_2 \times \text{REE} + \beta_3 \times \text{age} + \beta_4 \times \text{sex} + \beta_5 \times \text{site} \), where for sex, \( 0 = \text{male} \) and \( 1 = \text{female} \) and site was defined so that Nigeria was the reference group. \( r^2 = 0.66 \), root mean squared error = 6.8%.

### FIGURE 1

Cross-sectional relations between percentage body fat and activity energy expenditure adjusted for body size (AEE/body weight) among black women (\( \bullet; n = 28 \)) and men (\( \Delta; n = 30 \)) from Nigeria and black women (\( \circ; n = 22 \)) and men (\( \bigcirc; n = 12 \)) from the United States. The lines represent the regression equations for the women (---) and men (- - -) from both sites combined. Overall equation: percentage body fat = -0.14 AEE + 14.6 sex + 25.5, where \( r^2 = 0.61 \), root mean squared error = 7.3%, male sex = 0, and female sex = 1.
TABLE 5
Pearson correlation coefficients (and 95% CIs) for the relations between weight change per year and energy expenditure variables adjusted for body size and age in Nigerian women and men

<table>
<thead>
<tr>
<th></th>
<th>Nigerian women (n = 23)</th>
<th>Nigerian men (n = 24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>REE adjusted for FFM (MJ/d)</td>
<td>-0.44 (−0.73, −0.04)</td>
<td>0.07 (−0.34, 0.46)</td>
</tr>
<tr>
<td>AEE/body weight (kJ·kg⁻¹·d⁻¹)</td>
<td>-0.32 (−0.64, 0.10)</td>
<td>0.02 (−0.38, 0.42)</td>
</tr>
<tr>
<td>AEE adjusted for body weight (MJ/d)</td>
<td>-0.37 (−0.68, 0.05)</td>
<td>-0.05 (−0.44, 0.36)</td>
</tr>
<tr>
<td>TDEE adjusted for REE (MJ/d)</td>
<td>-0.31 (−0.64, 0.12)</td>
<td>-0.06 (−0.45, 0.35)</td>
</tr>
</tbody>
</table>

¹REE, resting energy expenditure; FFM, fat-free mass; AEE, activity energy expenditure; TDEE, total daily energy expenditure.

²P = 0.03.

These findings are in contrast with those of Esparza et al (16), who reported significantly higher levels of energy expenditure and lower levels of body fat among Pima Indians living a traditional lifestyle in rural Mexico than in Pima Indians living in the United States. This difference in energy expenditure between the 2 groups of Pima Indians was consistent regardless of whether physical activity expenditure was expressed as TDEE adjusted for FFM or REE, as AEE adjusted for body weight, or as PAL. The findings among the Pima Indians support the concept that as populations move from traditional agriculture to a more Western and mechanized lifestyle, AEE decreases and in turn results in an increase in the incidence of obesity; however, our data do not support this finding. The findings of the present study suggest that obesity, at least at the population level, is probably due to many factors, including levels of AEE, dietary patterns, and the composition of diets. In addition, closer study of activity patterns and physical fitness may yield information on the relation between physical activity and obesity at the population level not provided by this DLW study. A larger sample size may also provide more information.

Although the energy expenditure data presented herein did not differ significantly from data derived from comparable studies in which DLW was used to measure energy expenditure in white and black participants from Western societies (6, 33, 40, 41), the mean PAL values for the Nigerian sample in the present study were lower than those measured in a Gambian population, particularly in men (42, 43). Although one-half of our Nigerian sample consisted of rural farmers and the DLW measurements were taken at 3 separate times throughout the year—after the rainy season (harvesting), during the early rainy season (planting and tending crops), and during the dry season (clearing of land)—the PAL values did not differ significantly by season. The mean PAL in Nigerian men was 1.70 compared with 3.02 in male agricultural laborers in the Gambia. However, the measured energy expenditure level may not have represented the usual energy expenditure of the Gambian men because they had been engaged in experimental tests of work performance at the time the measurements were made (43). The Gambian and Nigerian women had much more comparable mean PAL values: 1.86 and 1.78, respectively. Unlike the reports from the Gambia, population mean weight did not differ significantly by season and there was no evidence of a “hungry” season (42; A Adeyemo, A Luke, unpublished observations, 1998–2000). These studies indicate that physical activity expenditures differ throughout developing countries as they do elsewhere, depending on the occupations of the population studied.

Few longitudinal studies of the effect of physical activity on naturally occurring weight change in free-living humans have been published. Of the few such studies that have been published, the analytic methods used and the conclusions reached by each have differed. In a longitudinal study of prepubescent white children, no relations between weight change and adjusted TDEE, REE, or AEE were observed (13). In contrast, lower TDEEs and REEs were shown to predispose adult Pima Indians to greater weight gain (11). In the present study, the very small number of longitudinal observations in the US sample led us to analyze the Nigerian data separately. The energy covariates were consistently negative in the models tested, suggesting that short-term weight change in black adults is associated with low levels of energy expenditure. As more and longer longitudinal studies of weight change are conducted, this association should become clearer.

In conclusion, the present study provides evidence that energy expended in physical activity is strongly associated with adiposity among populations of West African origin and may predict weight gain in individuals. Investigation of additional environmental factors, such as types and patterns of activity, physical fitness levels and diet, will be necessary, however, to elucidate the causes of the different prevalences of obesity across societies.

REFERENCES


