Substrate-energy metabolism and metabolic risk factors for cardiovascular disease in relation to fetal growth and adult body composition


Institute of Human Nutrition, University of Southampton, Southampton General Hospital; Medical Research Council, Epidemiology Resource Centre, University of Southampton, Southampton, United Kingdom; and Department of Nutritional Sciences, Rutgers, the State University of New Jersey, New Brunswick, New Jersey

Submitted 1 December 2005; accepted in final form 2 March 2006

Kensara, Osama A., Steve A. Wooton, David I. W. Phillips, Mayank Patel, Daniel J. Hoffman, Alan A. Jackson, Marinos Elia, and the Hertfordshire Study Group. Substrate-energy metabolism and metabolic risk factors for cardiovascular disease in relation to fetal growth and adult body composition. Am J Physiol Endocrinol Metab 291: E365–E371, 2006. First published March 28, 2006; doi:10.1152/ajpendo.00599.2005.—The effect of fetal programming on intermediary metabolism is uncertain. Therefore, we examined whether fetal programming affects oxidative and nonoxidative macronutrient metabolism and the prevalence of the metabolic syndrome in adult life. Healthy older men, aged 64–72 years, with either a lower birth weight (LBW, ≤25th %ile; n = 16) or higher birth weight (HBW, ≥75th %ile; n = 13) had measurements of 1) net oxidative metabolism using indirect calorimetry before and for 6 h after a mixed meal (3,720 kJ) and 2) postprandial oxidation of exogenous [13C]palmitic acid. Body composition was measured using dual-energy X-ray absorptiometry. After adjustment for current weight and height, the LBW group had a lower resting energy expenditure (REE) in the preprandial (4.01 vs. 4.54 kJ/min, P = 0.015) and postprandial state (4.60 vs. 5.20 kJ/min, P = 0.004), and less fat-free mass than the HBW group. The BW category was a significant, independent, and better predictor of REE than weight plus height. There were no significant differences between groups in net oxidative and nonoxidative macronutrient (protein, fat, carbohydrate) metabolism (or of exogenous [13C]palmitate) or in the prevalence of the metabolic syndrome, which was present almost twice as commonly in the LBW than in the HBW group. The study suggests that fetal programming affects both pre- and postprandial EE in older life by mechanisms that are at least partly related to the mass of the fat-free body. BW was found to be a significant predictor of REE that was independent of adult weight plus height.

energy expenditure; birth weight; body composition; fat; fat-free mass; oxidation

Environmental factors operating during fetal growth are believed to influence the risk of cardiovascular disease, diabetes, hypertension, and obesity in adult life. Despite increasing interest in this field (17, 19, 24), there is surprisingly little information about programming of even the most basic aspects of human metabolism, such as selection of endogenous and exogenous fuels, oxidative and nonoxidative metabolism of fat carbohydrate and protein, and lipoprotein metabolism. There is also little information about the extent to which any programmed metabolic processes are linked to body composition, fat distribution, and health risk. Although several studies have reported a link between birth weight and glucose tolerance (12, 16, 23), there is little information as to whether events in early life also affect the way adults handle other fuels, mixture of fuels such as those present in a mixed meal, and whether any such differences are related to percent body fat and its distribution within the body. Furthermore, despite the interest in early-life programming of adiposity and its comorbidities, there is surprisingly little information on energy homeostasis and the components of energy balance.

Reduced fetal growth, manifesting itself as lower birth weight, has been repeatedly reported to be associated with reduced adult weight and height (1, 13, 20, 21, 27, 32, 41). We have contributed to this literature by reporting that older Englishmen with lower BW have more percent fat and less lean tissue [measured by dual-energy X-ray absorptiometry (DEXA)] and a more central fat distribution than those with a higher birth weight, even after adjustment for weight and height or body mass index (BMI) (31). Such differences in percent fat and its distribution are expected to influence risk of developing cardiovascular disease and diabetes. Differences in fat-free mass (FFM) are also expected to influence resting energy expenditure (REE) (5, 7), the major component of total energy expenditure. This study aimed to examine whether birth weight is related to net oxidative and nonoxidative fuel metabolism before and after a mixed meal and to the oxidation of exogenously administered labeled lipid. It also aimed to assess whether any such birth weight differences were linked to body composition and prevalence of metabolic syndrome.

Subjects and Methods

Subjects. Thirty-two healthy adult Caucasian men (Table 1) aged 64–72 yr were recruited for investigations at the Wellcome Trust Clinical Research Facility, Southampton General Hospital. The subjects were chosen randomly among those below the 25th percentile of birth weight (<3.23 kg [7.1 lb]) or above the 75th percentile (>3.89 kg [8.5 lb]; mean weight ± SE: 2.76 ± 0.06 vs. 4.24 ± 0.06 kg]), and 29 of them had metabolic rate measurements. Ethical approval for the study was obtained from the Southampton and South West Hampshire research Ethics Committee, and written informed consent was obtained from all subjects. The subjects were asked to undertake normal activities, to have a normal dietary intake for the 3 days before the study, and to report any deviations from these instructions. Weight was measured to the nearest 0.1 kg using the Seca 708 electronic weighing scale and height to the nearest 0.1 cm using the Seca electronic stadiometer (Seca, Medical Scales and Measurement Sys-
Body composition. Body composition was measured with DEXA Hologic Delphi, which was analyzed using software v. 12.2. Whole body muscle mass was estimated using the equation of Kim et al. (18), which was established by relating DEXA measurements of appendicular (limb) fat-free soft tissue with whole body measurements of muscle mass obtained using magnetic resonance imaging in healthy adults. Fat distribution was estimated as the nonlimb-to-limb fat mass ratio, trunk-to-limb fat mass ratio, and abdominal-to-limb fat mass ratio. The fat masses in the trunk and limbs were those reported by the DEXA machine, whereas the abdominal fat mass had to be established. First, the region of interest was identified as the area between the top border of the iliac crest to the lower border of the fourth lumbar vertebra (26). The region of interest was identified manually to the nearest pixel (1.3035 cm) and its composition then estimated using the software program vs. 12.2 of Hologic Delphi (intraobserver coefficient of variation = 3.5%).

REE. REE was measured using an open-circuit indirect calorimetry system that employed a ventilated hood system (GEM calorimetry, Europa Scientific, Crewe, UK). The machine was calibrated using reference gases before each measurement. Recovery of CO₂ and O₂ consumption were assessed using the alcohol burn technique. Gaseous exchange was measured for a period of 20–25 min after an overnight fast (12–14 h). After this, the subjects ate a meal containing 3,720 kJ, of which 15% was derived from protein, 40% from carbohydrate, and 45% from fat. It also contained 700 mg of [13C]palmitic acid (99 atom percent excess; Cambridge Isotopes) mixed with a lipid-casein-glucone-sucrose emulsion. Repeat measurements of REE (postprandial REE) were undertaken every 60 min for 6 h after the meal. All measurements were undertaken with subjects in the recumbent position in a quiet room, at an ambient temperature of 22–25°C. Samples of end tidal expired air breath were collected in a bag (Quintron, Milwaukee, WI) before the test meal and at hourly intervals for the next 6 h after the test meal. A venous blood sample was taken from the antecubital vein, immediately centrifuged, and stored at −80°C for subsequent analysis. After this part of the study was completed, the subjects remained in the metabolic research facility (including an overnight stay), were free to move about, and were given an evening meal containing 1,730 kJ, with 13% from protein. A 24-h urine collection was obtained during their stay in the metabolic facility.

Analyses and calculations. The following analytes were measured by routine methods using the Kone Auto analyzer (Labmedics, Birmingham, UK): glucose, nonesterified fatty acids (NEFA ACS-ACOD kit; Wako Chemicals, Lewes, UK), triacylglycerol (TAG), and HDL-cholesterol (reagent kits from Konelab Labmedics, Manchester, UK).

The enrichment of end-expiratory 13CO₂ was measured by continuous-flow isotope ratio mass spectrometry (CF-IRMS, 20/20 IRMS-GSL interface; Europa, Scientific, Crewe, UK). A 24-h urine collection was also obtained for measurement of urine urea and ammonia (kit no. B01-4132-01; Bayer, Berkshire, UK), and creatinine (Jaffé reaction; Bayer kit no. AD286CR), which in combination were assumed to account for 95% of total urine N.

Energy expenditure was calculated using the equations of Elia and Livesey (10).

Various models of oxidative metabolism were established, assuming that 1) postprandial protein oxidation accounted for 15, 22.5, and 30% of postprandial REE; and 2) total 24-h urine N was distributed between the two 6-h postprandial periods and the remaining 12-h period in the ratios of 1:1, 1:1.2, and 1:1.4. Appropriate equations for nitrate-exchange were also derived for measurement of uric acid and ammonia (kit no. B01-4132-01; Bayer, Berkshire, UK), and creatinine (Jaffé reaction; Bayer kit no. AD286CR), which in combination were assumed to account for 95% of total urine N.
where otherwise stated. Differences between groups were assessed using one-way analysis of variance (ANOVA), and analysis of covariance (ANCOVA) was used to adjust for covariates, such as weight and height or percent fat (lower and higher birth weight groups as fixed factors). Multiple regression analysis was also used to establish correlations and semipartial (part) correlations. The statistical analyses were carried out using SPSS statistical package v.12.0 (SPSS, Chicago, IL).

RESULTS

The mean ages of the lower and higher birth weight groups were virtually identical (67.6 vs. 67.5 yr). The lower birth weight group was also shorter, lighter, and had less FFM and muscle mass both before and after adjustment for weight and height (Table 1). Results of REE obtained by the different equations (including those assuming 15, 20, and 25% contribution of protein to REE) differed from each other by a mean of less than 0.5%. The results that follow are those obtained by assuming that total urine N was distributed between the pre- and postprandial states in the ratio of 1:1.2. The preprandial REE for the entire group [4.26 ± 0.13 (range 2.0) kJ/min] was 94 ± 2% of that predicted from weight and age category by the Schofield equation (33). The lower birth weight group had significantly lower values for pre- and postprandial REE even when controlling for weight and height (Table 3 and Fig. 1). This significance was lost when the results were adjusted for FFM in the preprandial state, although it persisted when adjusted for the mass of nonmuscular fat-free soft tissue (FFST) and ratio of muscle to FFST. When weight and height were used to predict preprandial REE in a multiple regression model (r = 0.460), the residual standard deviation was 0.470 kJ/min. When birth weight category was also added to the model, the residual standard deviation was reduced to 0.424 kJ/min (and overall r increased to 0.617). Birth weight category alone was found to be a better predictor of preprandial REE than weight plus height. It was also found to be a better independent predictor than weight and height (semipartial r²; Fig. 2). The same was true of postprandial REE (Fig. 2).

No significant differences were found between groups in dietary induced thermogenesis (DIT) over the 6-h study period (average of 0.566 ± 0.077 vs. 0.661 ± 0.087 kJ/min after adjustment for weight and height, P = 0.464), corresponding to 5.59 ± 0.75 vs. 6.41 ± 0.85% (P = 0.464) of the dietary energy intake. There was also no significant difference in postprandial respiratory exchange ratio (Fig. 1). All models of fuel selection and oxidative metabolism failed to show significant differences between groups in either the pre- or postprandial state. Figure 3 is typical in showing the results obtained using one such model (oxidative metabolism calculated from nonmuscular fat-free soft tissue (FFST) and ratio of muscle to FFST).
gaseous exchange and urine N), assuming that the net protein oxidation rate in the postprandial period was 1.2 times that in the preprandial period. Macronutrient oxidation rates (with the exception of carbohydrate oxidation in the preprandial state) tended to be lower in the lower birth weight group, as might be expected from the lower REE (the sum of energy expended from macronutrient oxidation) in the lower birth weight group. However, none of the values were significantly different from those in the higher birth weight group, although in both the pre- and postprandial states in the higher birth weight group fat oxidation contributed to a mean of 3–6% more to REE, mainly at the expense of carbohydrate oxidation, which contributed 3–6% less to REE). No significant differences in macronutrient oxidation rates (or %contribution to REE) were obtained with other models of calculation of fuel selection. There was also no significant difference between groups in the circulating concentrations of glucose, NEFA, or TAG after an overnight fast or in the area (or incremental area) under the concentration-time curve after meal ingestion (with or without adjustment for weight + height; Table 4).

The prevalence of the metabolic syndrome calculated using ATPIII-BMI25 criteria [based on BMI, blood pressure, plasma glucose, TAG, and HDL-cholesterol (36)] was almost twofold greater in the lower than in the higher birth weight group (68.8 vs. 38.5%); but with the small number of subjects involved in this study, the difference was not significant (P = 0.105).

Fig. 1. Changes in resting energy expenditure (REE; top) and respiratory exchange ratio (RER; bottom) after meal ingestion. Results were calculated assuming that net protein oxidation (calculated from N excretion) occurred at a rate 20% higher than the preprandial state and are adjusted for weight and height. Preprandial measurements are indicated at time 0 h. ●, Higher birth weight group (HBW); □, lower birth weight group (LBW). Values are means ± SE. Results are adjusted for weight and height.

Fig. 2. Independent and combined contributions of birth weight category and height + weight to preprandial (top) and postprandial (0–6 h; bottom) REE.
was substantial and could explain a greater proportion of the birth weight category on REE in this group of individuals. Indeed, the predictive effect of birth weight was found to have more fat and less FFM, which is known to be an important determinant of REE. The lower birth weight group is not surprising. Second, even after adjustment for weight and height, the lower birth weight group was shorter and lighter and have less FFM than those with a higher birth weight, in keeping with other studies (1, 13, 20, 21, 27, 32, 41). Because body mass and, particularly, FFM are major determinants of REE, the lower REE in the lower birth weight category was found to be greater than that of weight and height in combination [much of the variability due to weight plus height could also be accounted by birth weight (Fig. 2)]. The residual standard deviation (0.460 kJ/min) obtained by regressing weight and height on REE was very similar to that obtained with the original Schofield dataset for men over the age of 60 yr (0.476 kJ/min), but it reduced to 0.424 kJ/min when birth weight was added to the predictor variables. In our study, in which the mean REE was 4.26 kJ/min, 25% of the variance in preprandial REE was explained by weight and height, which is lower than the value of 34% obtained in a group of 147 healthy Caucasian older men aged over 60 yr [mean age 72 yr (SD 6.68)]; REE (kJ/min), 4.48 (SD 0.61 and residual SD 0.50, in a regression model with weight and height as predictors of REE; M. Elia, unpublished results). This difference may be at least partly due to the smaller range in REE in our study (2.0 kJ/min) than in the group of 147 men (3.3 kJ/min). These considerations taken together suggest that REE and predictions of REE based on weight and height are similar in our subjects as in other groups of older men.

In normal adults, ~60% of the preprandial REE is accounted for by the liver, brain, heart, and kidneys, which account for only ~5–6% of body weight (6, 7). Muscle, which accounts for more than one-half of FFM, has a lower REE (per kg muscle) than the body as a whole (per kg body wt) and is responsible for only ~20% of REE. However, it is theoretically possible for differences in metabolic rates to occur as a result of not only variations in lean body mass but also variations in the proportion of tissues that make up lean body mass, as well as variations in tissue-specific metabolic rates. The mass and metabolic rate of organs were not measured in this study, but the tendency for REE to be lower in the lower than in the higher birth weight group, even after adjustment for mass of nonmuscular tissues and ratio of muscle to nonmuscular FFST, suggests that this is a possibility. The estimation of muscle mass is indirect and based on prediction equations obtained in another group of studies; therefore, relationships involving muscular and nonmuscular tissues require further investigation using more direct techniques.

**DISCUSSION**

This study in older Caucasian men has identified some functional metabolic correlates to body composition that are linked to fetal growth (birth weight). At least two reasons could help explain the lower REE in adults with lower than higher birth weight. First, individuals with a lower birth weight were found to be shorter and lighter and have less FFM than those with a higher birth weight, in keeping with other studies (1, 13, 20, 21, 27, 32, 41). Because body mass and, particularly, FFM are major determinants of REE, the lower REE in the lower birth weight group is not surprising. Second, even after adjustment for weight and height, the lower birth weight group was found to have more fat and less FFM, which is known to be an important determinant of REE. Indeed, the predictive effect of the birth weight category on REE in this group of individuals was substantial and could explain a greater proportion of the variability in both pre- and postprandial REE than weight and height together. Furthermore, the independent contribution of the birth weight category was found to be greater than that of weight and height in combination [much of the variability due to weight plus height could also be accounted by birth weight (Fig. 2)]. The residual standard deviation (0.460 kJ/min) obtained by regressing weight and height on REE was very similar to that obtained with the original Schofield dataset for men over the age of 60 yr (0.476 kJ/min), but it reduced to 0.424 kJ/min when birth weight was added to the predictor variables. In our study, in which the mean REE was 4.26 kJ/min, 25% of the variance in preprandial REE was explained by weight and height, which is lower than the value of 34% obtained in a group of 147 healthy Caucasian older men aged over 60 yr [mean age 72 yr (SD 6.68)]; REE (kJ/min), 4.48 (SD 0.61 and residual SD 0.50, in a regression model with weight and height as predictors of REE; M. Elia, unpublished results). This difference may be at least partly due to the smaller range in REE in our study (2.0 kJ/min) than in the group of 147 men (3.3 kJ/min). These considerations taken together suggest that REE and predictions of REE based on weight and height are similar in our subjects as in other groups of older men.

In normal adults, ~60% of the preprandial REE is accounted for by the liver, brain, heart, and kidneys, which account for only ~5–6% of body weight (6, 7). Muscle, which accounts for more than one-half of FFM, has a lower REE (per kg muscle) than the body as a whole (per kg body wt) and is responsible for only ~20% of REE. However, it is theoretically possible for differences in metabolic rates to occur as a result of not only variations in lean body mass but also variations in the proportion of tissues that make up lean body mass, as well as variations in tissue-specific metabolic rates. The mass and metabolic rate of organs were not measured in this study, but the tendency for REE to be lower in the lower than in the higher birth weight group, even after adjustment for mass of nonmuscular tissues and ratio of muscle to nonmuscular FFST, suggests that this is a possibility. The estimation of muscle mass is indirect and based on prediction equations obtained in another group of studies; therefore, relationships involving muscular and nonmuscular tissues require further investigation using more direct techniques.

**Table 4. Circulating concentrations of glucose, TAG, and NEFA, and concentration-time AUC iAUC after meal ingestion, according to BW group**

<table>
<thead>
<tr>
<th></th>
<th>LBW (n = 16)</th>
<th>HBW (n = 13)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>After overnight fast</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose, mmol/l</td>
<td>6.16±0.32</td>
<td>6.00±0.35</td>
<td>0.746</td>
</tr>
<tr>
<td>TAG, mmol/l</td>
<td>1.52±0.20</td>
<td>1.31±0.15</td>
<td>0.426</td>
</tr>
<tr>
<td>NEFA, mmol/l</td>
<td>0.43±0.04</td>
<td>0.41±0.04</td>
<td>0.716</td>
</tr>
<tr>
<td>After meal ingestion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUC, mmol·h·liter⁻¹</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose</td>
<td>40.19±1.71</td>
<td>35.97±1.89</td>
<td>0.109</td>
</tr>
<tr>
<td>TAG</td>
<td>11.51±1.66</td>
<td>10.97±1.34</td>
<td>0.807</td>
</tr>
<tr>
<td>NEFA</td>
<td>1.76±0.10</td>
<td>1.77±0.40</td>
<td>0.969</td>
</tr>
<tr>
<td>iAUC, mmol·h·liter⁻¹</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose</td>
<td>6.54±1.42</td>
<td>5.91±1.17</td>
<td>0.743</td>
</tr>
<tr>
<td>TAG</td>
<td>2.38±0.74</td>
<td>3.11±0.84</td>
<td>0.517</td>
</tr>
<tr>
<td>NEFA</td>
<td>0.91±0.18</td>
<td>0.93±0.16</td>
<td>0.949</td>
</tr>
</tbody>
</table>

Results are expressed as means ± SE. TAG, triacylglycerol; NEFA, nonesterified fatty acids; AUC, area under the curve; iAUC, incremental AUC.
The difference in REE between the lower and higher birth weight groups was observed not only in the preprandial period but also the postprandial period. This difference, which was present both before and after adjustment for weight and height, could provide an explanation for the greater reported adiposity in adults with lower than higher birth weight. However, the link between REE and subsequent weight gain is not entirely clear. Although some studies have reported that adults with a low REE have greater weight gain over a period of years (3, 29, 30) than those with a high REE, this has not been corroborated by other studies (34, 38, 39). This may be partly because REE is only one component of energy expenditure, the most variable being physical activity, and partly because predisposition to weight gain is obviously confounded by differences in energy intake. Unfortunately, we did not undertake an analysis of the habitual energy intake of our subjects. However, animal studies suggest that alterations in fetal and neonatal growth can lead to alterations in appetite in later life (4, 22), possibly as a result of effects on the hypothalamus (22). In addition, there is the possibility that physical activity and/or fitness are programmed during fetal life, as suggested a retrospective study of aerobic fitness, which was assessed using endurance and exhaustion tests, in 12-yr-old boys (2). The interactions between REE, physical activity, and appetite determine the manifestations of obesity and weight gain. The distribution of these between genetic and environmental factors, and between programmed and nonprogrammed environmental factors, remains uncertain.

Another relevant consideration is that most studies examining the relationship between REE and subsequent weight gain have generally adjusted REE for baseline differences in body composition, whereas in our study differences in REE between groups are considered to be at least partly due to differences in body composition (FFM) that persist even after adjustment for weight and height. Fat distribution was not found to be associated with altered REE, in keeping with some (25, 37) but not all previous reports (40) in which measurements of REE [or sleeping metabolic rate (37)] were made in relation to anthropometric measures of fat distribution between trunk and upper legs.

In contrast to our study, in which REE tended to be lower in the lower than in the higher birth weight group, after controlling for FFM, a previous study (41) reported a tendency for sleeping metabolic rate to be lower in adults with higher than lower birth weight. This study differed from ours in several ways: it involved obese (mean BMI 33.5 kg/m²) rather than nonobese individuals, Pima Indians rather than Caucasians, young adult men and women (mean age 25 yr) rather than older men, measurements of energy expenditure made during sleep rather than in the woken state, and measurements that began 3.5 h after a snack and 6.5 h after the start of a meal rather than 12–14 h after an overnight fast. Another study (11) involving Finnish adults reported higher REE per kilogram of body weight in those with a lower than higher birth weight. However, REE per kilogram of FFM typically decreases as FFM gets larger (5), probably because of the smaller percent contribution of organ mass to FFM as FFM increases (7, 14). This means that the comparison of REE per kilogram of FFM between birth weight categories is likely to be biased toward a higher value in the lower birth weight group, which was reported to have a significantly smaller FFM.

The present study also found a higher postprandial REE in the lower than in the higher birth weight group, which could be almost entirely accounted for by the differences in preprandial REE. No evidence was found of a significant effect of birth weight category on dietary induced thermogenesis, oxidative or nonoxidative metabolism of fat, carbohydrate and protein, or nutrient balance following ingestion of a mixed meal of standard composition. There was a tendency for fat oxidation to be higher in the higher than in the lower birth weight group, but this did not reach statistical significance. In addition, because the higher birth weight group had a higher REE, the difference in percent contribution of fat oxidation to REE was much less marked between the groups. The calculated nutrient balances were based on estimates rather than measurements of net protein oxidation in both pre- and postprandial states. Nevertheless, different models of nutrient balance that assumed different contributions of protein to total REE (15, 20, and 25%) and different ratios of pre- to postprandial net protein oxidation also showed no significant differences between the groups. Furthermore, the oxidation of exogenous fat, which was assessed using labeled [13C]palmitate and assumptions that were independent of protein oxidation, showed no significant difference between the lower and higher birth weight groups, although, as with net fat oxidation, there was a tendency for more fat to be oxidized in the higher birth weight group. The recovery of labeled [13CO2] in breath does not take into account the labeled CO2 produced by oxidation and still within the body pool. However, the enrichment of [13CO2] at the end of 6 h, which reflects the enrichment of the circulating CO2 pool (9), did not differ significantly between the two groups.

This study also obtained preliminary information on the link between birth weight and metabolic risk factors for cardiovascular disease and the way in which they are related to body composition. Although differences in risk factors might be expected from previous reports of body composition, as well as from this study, which found differences between groups in percent fat, fat distribution, more central distribution, and fat/muscle ratio, lipid profile, glucose intolerance, and prevalence of metabolic syndrome did not differ significantly between the groups. The metabolic syndrome was found to be almost twice as common in the lower vs. higher birth weight group, but due to the small number of subjects the difference did not reach statistical significance. Multiple factors are known to influence each of the metabolic risk factors, which explains the low correlations between individual biochemical risk factors and BMI (or waist-to-hip ratio), even when the range of values for the anthropometric variables is large (35). Therefore, it is possible that much larger sample sizes are required to demonstrate any real link that may exist between birth weight and these risk factors. In addition, a medium birth weight group needs to be included in the analyses to establish whether the relationships are linear or nonlinear.

It is clear that this study needs to be extended to include women, different age categories, different ethnic groups, and all birth weight groups, not just the extreme ones, which are probably more likely to yield significant differences. Finally, because birth weight is a crude overall measurement of fetal growth, it is possible that measurements of the pattern or pathways of fetal growth and composition can shed much more light on programming of adult body structure and metabolic function.
GRANTS

This work was carried out using core funds from the Institute of Human Nutrition and Epidemiology Research Centre, a grant from Unm Al-Qura University, Saudi Arabia, which supported O. Kensara during his PhD Study at the University of Southampton, and National Institute of Child Health and Human Development Grant No. 1RO1 HD-41107-01 to D. I. W. Phillips.

REFERENCES

2. Boreham CA, Murray L, Dedman D, Davey Smith G, Savage JM, and Strain JJ. Birthweight and aerobic fitness in adolescents: the Northern Ireland Young Hea...