Energy intake, not energy output, is a determinant of body size in infants[1–3]

Albert J Stunkard, Robert I Berkowitz, Virginia A Stallings, and Dale A Schoeller

ABSTRACT

Background: It has been proposed that the primary determinants of body weight at 1 y of age are genetic background, as represented by parental obesity, and low total energy expenditure.

Objective: The objective was to determine the relative contributions of genetic background and energy intake and expenditure as determinants of body weight at 1 y of age.

Design: Forty infants of obese and 38 infants of lean mothers, half boys and half girls, were assessed at 3 mo of age for 10 risk factors for obesity: sex, risk group (obese or nonobese mothers), maternal and paternal body mass index, body weight, feeding mode (breast, bottle, or both), 3-d energy intake, nutritive sucking behavior during a test meal, total energy expenditure, sleeping energy expenditure, and interactions among them.

Results: The only difference between risk groups at baseline was that the high-risk group sucked more vigorously during the test meal. Four measures accounted for 62% of the variability in weight at 12 mo: 3-mo weight (41%, $P = 0.0001$), nutritive sucking behavior (9%, $P = 0.0002$), 3-d food intake (8%, $P = 0.0002$), and male sex (3%, $P = 0.05$). Food intake and sucking behavior at 3 mo accounted for similar amounts of variability in weight-for-length, body fat, fat-free mass, and skinfold thickness at 12 mo. Contrary to expectations, neither total nor sleeping energy expenditure at 3 mo nor maternal obesity contributed to measures of body size at 12 mo.

Conclusions: Energy intake contributes significantly to measures of body weight and composition at 1 y of age; parental obesity and energy expenditure do not. *Am J Clin Nutr* 1999;69:524–30.

KEY WORDS Obesity, body size, infants, risk factors, genetic influence, energy intake, energy expenditure, nutritive sucking behavior

INTRODUCTION

This report describes a prospective, longitudinal study to determine risk factors for weight gain of infants at high or low risk of obesity by virtue of their mothers' obesity or leanness. Studies of persons at high risk of a certain disorder before the onset of the disorder are powerful tools for investigating etiology, but they are rare in the field of obesity. Therefore, one such study of 3-mo old infants born to overweight or lean mothers has received considerable attention (1). In that study, 6 infants with both low total energy expenditure (TEE) and overweight mothers became overweight as indicated by exceeding the 90th percentile of weight-for-height at one or more assessments during the first year of life, in contrast with 12 infants without these characteristics. Two subsequent longitudinal studies from the same laboratory, one by Davies et al (2) of 33 infants and one by Wells et al (3) of 30 infants, found that TEE at 3 mo of age showed no relation to measures of body fatness at 2–3.5 y of age. Furthermore, Davies et al (4) found no relation between parental body mass index (BMI; in kg/m^2) and TEE of infants at 3 mo of age. The predictive value of energy intake has also been a source of disagreement. Thus, in a later report by Roberts (5), 6 infants in the original high-risk study who became overweight were consuming 42% more energy at 6 mo of age than were the 12 infants who remained lean. In a breast-feeding study of 87 infants, Dewey et al (6) found that energy intake at 6 mo predicted body fatness at 1 y of age. By contrast, Wells et al (7) reported that the energy intake of twenty 3-mo-old infants was not an important determinant of body fatness at 2–3.5 y of age.

The present study was designed to resolve the conflict concerning the role of energy expenditure and energy intake in the prediction of body size in the first year of life. We determined TEEs, sleeping energy expenditures, energy intakes, and nutritive sucking behavior at 3 mo of age in 40 infants born to obese mothers and 38 infants born to lean mothers and determined measures of infant body composition at 3 and 12 mo of age.

SUBJECTS AND METHODS

Subjects

We screened 1219 white mothers to enroll 82 infants from 2 newborn nurseries, 7 obstetric practices, 4 pediatric practices,

[1] From the Departments of Psychiatry and Pediatrics, School of Medicine, University of Pennsylvania, Philadelphia; the Children's Hospital of Philadelphia; and the Clinical Nutrition Research Unit, University of Chicago Hospitals.

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[3] Address reprint requests to AJ Stunkard, Department of Psychiatry, University of Pennsylvania, 3600 Market Street, Room 734, Philadelphia, PA 19104-2648. E-mail: stunkard@mail.med.upenn.edu.

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and local referrals. The study group was confined to white infants because nonwhite infants have different growth patterns than white infants (8–10). The mothers' obstetricians reported that all mothers experienced a normal pregnancy, labor, and delivery. Inclusion criteria for the mothers were as follows: a prepregnancy BMI greater than the 66th percentile or less than the 33rd percentile for their age group (11), birth to a full-term infant with no illness or disability, no gestational diabetes, and ≥18 y of age. In addition, the families had to express a high degree of commitment to the study, which had been described as being long. Exclusion criteria for the infants were as follows: a gestational age <36 or >42 wk and a low or high weight-for-gestational-age. Data were not available at 12 mo for 1 infant from the high-risk group and for 3 infants from the low-risk group; therefore, this report is based on data for 40 high-risk and 38 low-risk infants. Information about paternal height and weight was reported by the father or mother.

Informed consent was obtained from the parents and the protocol was approved by the Institutional Review Boards of the University of Pennsylvania and of the Children's Hospital of Philadelphia. The study was conducted in the Nutrition and Growth Laboratory of the Children's Hospital of Philadelphia.

Body size and composition

Infant birth weight was obtained from hospital records. At 3 and 12 mo of age, weight was measured in triplicate with a digital scale (model 4800; Scaletronix, Carol Stream, IL); length with a Holtain Infant Length Board (Crymych, United Kingdom) (12); skinfold thicknesses with a Holtain Skinfold Caliper (Crymych) at the biceps, triceps, subscapular, and suprailiac sites; and body fat with total body electrical conductivity (HP_2-TOBEC; EM-SCAN Incorporated, Springfield, IL) (13).

Energy intake

Three feeding modes of the 3-mo-old infants were assessed and categorized: *1*) breast-feeding—all nourishment from breast milk; *2*) formula feeding—all nourishment from infant formula, delivered by a bottle; and *3*) combined breast-feeding and bottle-feeding. Energy intake was assessed in 2 ways: from food intake and from nutritive sucking behavior.

Food intake was determined from weighed food records (14) kept by the parents for 3 d during the week after the body-composition assessment. Parents were carefully instructed in the technique of weighing and recording all food intake. Bottles of formula were weighed before and after each feeding with a digital scale (model 6025; Sunbeam, Hattiesburg, MS) accurate to 1 g. Breast-fed infants were weighed unclothed before and after feeding with an integrating scale (model IP65, type I-15; Sartorius, Edgewood, NY) adapted with infant bassinets and accurate to 1 g. Food records were analyzed by a registered research dietitian, who was blinded to risk group, using the FOOD PROCESSOR II PROGRAM (ESHA Research, Salem, OR).

Nutritive sucking behavior was measured in the laboratory while the 3-mo-old infants were fed a midday test meal from an automated nutritive sucking apparatus (15). To maximize acceptance, nipples were constructed from standard, commercially available baby bottle nipples (Evenflo Products Co, Canton, GA; Gerber Products Co, Fremont, MI; and Playtex Products Inc, Westport, CT) adapted to deliver identical flow rates (16). Infants were fed either expressed breast milk or their customary formula by their mothers (or usual caregivers) with their customary nipple type. Five sucking variables were assessed during the test meal: total intake (in g) of formula or milk, total number of sucks, overall sucking rate (in sucks/s), suck rate within sucking bursts (in sucks/s), and maximum sucking pressure (in mm Hg). Because these variables were highly correlated, one representative value (total number of sucks) was used in the analyses.

Sleeping energy expenditure

Sleeping energy expenditure was measured with open-circuit indirect calorimetry by using a computerized metabolic cart (model 2900Z; SensorMedics, Yorba Linda, CA) with a clear, ventilated hood placed over the head of the infant to sample gases. Infants entered the Growth and Nutrition Laboratory in the late morning and measurements were taken ≥1 h after the midday feeding while the infant was in natural sleep. The first 10 min of the 60-min assessment were considered a period of acclimation by the child; therefore, measurements during this time were not used in the calculations. Sleeping energy expenditures were reviewed and any interval associated with documented movement and waking or with changes in sleeping energy expenditures was removed from the analysis.

The TEE of the 3-mo-old infants was measured over 7 d with the doubly labeled water method. Isotopes were analyzed in the laboratories of the University of Chicago. Doubly labeled water is a nonintrusive, indirect calorimetric method that uses stable isotopes and is accurate and precise in infants (17–19). On the same day that sleeping energy expenditures were measured, a baseline urine specimen was collected and 0.25 g $H_2{}^{18}O$ and 0.15 g ^2H_2O/kg body wt were given orally. Any spillage of the dose was collected on absorbent paper and weighed. Two urine samples were collected 4–6 h after administration and 2 more were collected in the morning before feeding, 6–8 d after the dose. Urine specimens were collected in dry paper diapers and frozen in zip-locked plastic bags. Samples not collected in the Growth and Nutrition Laboratory were picked up by research assistants. Urine was expressed from the diaper by pressure and frozen.

The isotope abundances in the urine samples were analyzed by mass spectrometry (20). Triplicate 2-μL aliquots of urine were vacuum distilled into quartz tubes and reduced to hydrogen over zinc at 500 °C. Aliquots (1.5 mL) of urine were equilibrated with carbon dioxide at a constant temperature and the resulting carbon dioxide was isolated. Gravimetric dilutions of the isotope-labeled water were analyzed by using the same methods. Isotopic enrichments were calculated relative to baseline, and the isotope-dilution spaces and elimination rates were calculated by using the slope-intercept method (16). Carbon dioxide production was calculated as follows:

$$rCO_2 = \text{TBW}(1.007k_o - 1.042k_h)/2.076 - 0.0246r_{Gf} \qquad (1)$$

where TBW is total body water (in mol), k_o and k_h are the respective isotope rates for oxygen and hydrogen, and r_{Gf} is the rate of fractionated water lost. For these infants, the latter was estimated to be 1.45TBW $(1.007k_o - 1.042k_h)/2.076$. Energy expenditure was calculated by using the modified de Weir equation (21), assuming a respiratory quotient of 0.85 (22). The average ratios of deuterium to ^{18}O dilution space were 1.04 ± 0.02 and 1.03 ± 0.01 in the high- and low-risk groups, respectively.

Statistical analysis

We first compared, with two-sample *t* tests, all variables related to weight and the possible influences on weight between high- and low-risk infants at 3 and 12 mo. Second, we estimated the relation among the variables measured at 3 and 12 mo by using Pearson correlation coefficients. Third, we evaluated by hierarchical linear regression analyses the independent contributions of the following unmodifiable variables: risk group, maternal and paternal BMI, sex, 3-mo weight, and sleeping energy expenditures on our predicted 12-mo outcomes (weight, weight-for-length, fat mass, fat-free mass, and sum of 4 skinfold-thickness measures). The modifiable variables feeding mode, 3-d food intake, and a representative measure of sucking behavior (total number of sucks during the laboratory meal) were then incrementally entered into the regression. A variable was kept in the model if the P value on entry was <0.10. A variable was removed from the regression if the P value was >0.10. The incremental variance (R^2) for each variable added to the model was computed. Model building proceeded in this manner until all significant predictors had been entered one at a time.

TEE measurements were available for only 42 subjects. Variables for these 42 subjects did not differ significantly from those for the 36 subjects for whom TEE measurements were not available. Data for these 42 subjects were entered into a separate regression. The presence of obese fathers in the sample made possible comparisons of alternative risk groups in addition to the original comparisons based solely on maternal obesity. First, we compared the characteristics of 20 infants with 2 obese parents with those of 30 infants with no obese parents. Second, we also compared a risk group of 28 infants with 1 obese parent. Analyses were conducted by using SAS (SAS/STAT *User's Guide*, 1989; SAS Institute, Inc, Cary, NC).

RESULTS

Comparison of the high- and low-risk groups

Characteristics of parents and their infants are presented in **Table 1**. Although selection was based only on the BMIs of the mothers, the BMIs of the fathers of the high-risk infants were significantly higher than those of the low-risk infants. There was no significant difference between the birth weights of the high- and low-risk infants.

There was no significant difference between the risk groups in body size or composition at any time during the first year and, despite an increase in weight, there was no significant change in percentage of body fat by TOBEC (**Table 2**). The striking similarities in the changes in weight-for-length and the sum of 4 skinfold-thickness measurements during the year are illustrated in **Figures 1** and **2,** respectively. There was also no significant difference between the high-risk (3 of 39, or 8%) and low-risk (5 of 38, or 13%) groups in the proportion of subjects who were at or above the 90th percentile of weight-for-length at 12 mo.

There was no significant difference in 3-d food intakes between the high- and low-risk groups (**Table 3**). The intraclass correlation of food intake among the 3 d was 0.67 ($P < 0.001$). Seventy-six infants accepted the laboratory test meal and, in contrast with the other measures, sucking behavior of the high-risk group was more vigorous than that in the low-risk group. The TEEs and sleeping energy expenditures of the 2 risk groups were almost identical at 3 mo of age, as was the measure of physical activity calculated from TEE minus sleeping energy expenditure (**Table 4**).

TABLE 1
Characteristics of parents and their infants

	High risk (n = 40)	Low risk (n = 38)
Maternal BMI (kg/m^2)	32.1 ± 5.9[1]	20.7 ± 2.8[2]
Maternal age (y)	31.7 ± 4.7	33.7 ± 5.5
Paternal BMI (kg/m^2)	27.6 ± 4.6	25.4 ± 2.4[3]
Male:female infants	20:20	19:19
Infant birth weight (kg)	3.5 ± 0.5	3.5 ± 0.4
Feeding mode (n)		
Breast fed	5	5
Formula fed	25	18
Both	10	15

[1] $\bar{x}$ ± SD.
[2,3] Significantly different from high risk: [2] $P < 0.001$, [3] $P < 0.01$.

Alternative risk-group comparisons

Once again, infants of the different risk groups did not differ significantly, except for the more vigorous sucking behavior by infants with obese mothers.

Prediction of body size

Because body weight, weight-for-length, and changes in these variables were not significantly different between the high- and low-risk groups (Table 2), we pooled the data from the 2 risk groups and calculated correlation coefficients among the variables measured at 3 and 12 mo. The significant intercorrelations among the risk factors at 3 mo of age, particularly between weight and TEE (r = 0.71, $P < 0.001$) and between weight and sleeping energy expenditure (r = 0.47, $P < 0.001$), are shown in **Figure 3**. Risk factors at 3 mo were also significantly correlated

TABLE 2
Measures of body size in infants at high and low risk of obesity at 3 and 12 mo of age and changes between 3 and 12 mo of age[1]

	High risk (n = 40)	Low risk (n = 38)
3 mo of age		
Weight (kg)	6.0 ± 0.8	6.1 ± 0.6
Length (cm)	61.1 ± 2.2	61.4 ± 1.9
Weight-for-length (kg/m)	9.8 ± 1.0	9.9 ± 0.9
Weight-for-length, percentile	53.4 ± 24.6	53.8 ± 24.0
Percentage body fat (%)[2]	24.1 ± 4.7	25.6 ± 3.7
Triceps skinfold thickness (mm)	8.7 ± 1.9	8.9 ± 1.4
Subscapular skinfold thickness (mm)	7.5 ± 1.8	7.4 ± 1.4
12 mo of age		
Weight (kg)	9.8 ± 1.1	9.7 ± 0.9
Length (cm)	77.2 ± 2.8	76.4 ± 2.3
Weight for length (kg/m)	12.7 ± 1.1	12.7 ± 0.9
Weight for length percentile[2]	37.7 ± 24.0	36.0 ± 22.2
Percentage body fat (%)	26.0 ± 3.5	27.0 ± 3.5
Triceps skinfold thickness (mm)	9.1 ± 1.7	9.1 ± 1.8
Subscapular skinfold thickness (mm)	6.7 ± 1.7	6.5 ± 1.5
Changes between 3 and 12 mo of age		
Weight (kg)	+3.8 ± 0.8 (2.3–5.8)	+3.6 ± 0.7 (2.3–5.0)
Weight-for-length (kg/m)	+2.8 ± 1.0 (1.2–5.8)	+2.8 ± 0.8 (1.3–4.9)

[1] $\bar{x}$ ± SD; range in parentheses. There were no significant differences between groups.
[2] Determined by total body electrical conductivity.

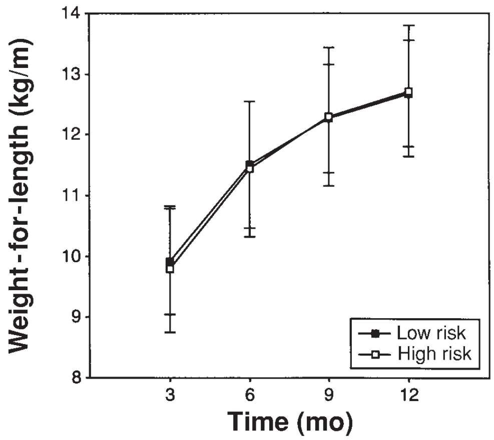

FIGURE 1. Mean (±SD) weight-for-length at 3, 6, 9, and 12 mo of age of infants at high and low risk of obesity. Values for the 2 risk groups are almost identical.

with weight at 12 mo, notably the well-recognized correlation between 3-mo and 12-mo weights ($r = 0.59$, $P < 0.0001$). Similar correlations were found for weight-for-length (**Figure 4**). The independent contributions of these highly intercorrelated risk factors were assessed by the regression analyses described above. Of the 10 risk factors, only 4 entered the regression that predicted 62% of the variability in weight and 54% of the variability in weight-for-length at 12 mo.

The strongest predictor was weight at 3 mo, which accounted for 41% of the variability in weight at 12 mo ($P = 0.0001$). Even after the influence of weight was accounted for, 2 independent measures of energy intake were strong predictors: total number of sucks (9%; $P = 0.0002$) and 3-d food intake (8%; $P = 0.0002$) (**Table 5** and Figure 3). Male sex accounted for a small amount of variability (3%; $P = 0.05$). Weight-for-length values were comparable (Table 5 and Figure 4). Notable among the predictors that did not enter the regression were risk group, maternal and paternal BMI, feeding mode, sleeping energy expenditure, and interactions among them. The separate regression for TEE showed that it did not predict weight, weight-for-length, fat, fat-free mass, or skinfold thickness at 12 mo.

To determine whether these findings applied also to the most overweight infants, we repeated the analysis on 6 infants with the same mean BMI (18.8) at 12 mo as that of the 6 heaviest infants in the study of Robert's et al (1). The results for our 6 infants were the same as for the sample as a whole: 3 of these infants were from the high-risk group and 3 were from the low-risk group, and, as with the entire sample, both TEEs and sleeping energy expenditures at 3 mo were positively correlated with body weight and weight-for-length at 12 mo.

Regression analyses also assessed the prediction of fat mass, fat-free mass, and the sum of 4 skinfold thicknesses at 12 mo of age. Initial (3 mo) fat mass accounted for 24% ($P = 0.0001$) of the variability in fat mass and food intake accounted for an additional 8% ($P = 0.003$). Initial (3 mo) fat-free mass accounted for 49% ($P = 0.0001$) of the variability in fat-free mass at 12 mo ($P = 0.0001$), whereas total sucks and food intake accounted for an additional 5% ($P = 0.008$) and 3% ($P = 0.02$), respectively. Neither TEE nor sleeping energy expenditure entered the regression.

Initial skinfold thickness accounted for 16% ($P = 0.003$) of the variance in skinfold thickness at 12 mo, whereas food intake and total sucks accounted for an additional 8% ($P = 0.007$) and 7% ($P = 0.01$), respectively. Again, neither TEE nor sleeping energy expenditure entered the regression.

TABLE 3
Energy intake and energy expenditure of infants at high or low risk of obesity at 3 mo of age[1]

	High risk ($n = 40$)	Low risk ($n = 38$)
Nutritive sucking		
Total intake (g/session)	150 ± 57	123 ± 48[2]
Total number of sucks	920 ± 559	620 ± 293[3]
Sucking rate (sucks/s)	0.75 ± 0.25	0.59 ± 0.26[3]
Sucking rate within sucking burst (sucks/s)	1.2 ± 0.3	1.0 ± 0.3[3]
Maximum sucking pressure (mm Hg)	201 ± 54	205 ± 51
Energy intake		
(kJ/d)	2261 ± 518	2337 ± 405
(kcal/d)	541 ± 124	559 ± 97

[1] $\bar{x}$ ± SD.
[2,3] Significantly different from high risk: [2] $P < 0.05$, [3] $P < 0.01$.

TABLE 4
Energy expenditure of high- and low-risk infants at 3 mo of age[1]

	High risk	Low risk
TEE		
n	19	23
(kJ/d)	1777 ± 326[2]	1743 ± 351
(kcal/d)	425 ± 78	417 ± 84
SEE		
n	34	32
(kJ/d)	1342 ± 263	1342 ± 201
(kcal/d)	321 ± 63	321 ± 48
TEE − SEE		
n	16	19
(kJ/d)	501 ± 262	435 ± 364
(kcal/d)	120 ± 58	104 ± 87

[1] There were no significant differences. TEE, total energy expenditure; SEE, sleeping energy expenditure.
[2] $\bar{x}$ ± SD.

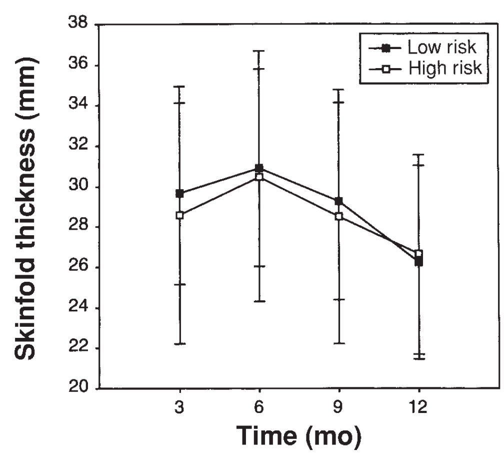

FIGURE 2. Mean (±SD) sum of 4 skinfold-thickness measures (biceps, triceps, subscapular, and suprailiac) at 3, 6, 9, and 12 mo of age of infants at high and low risk of obesity. Values for the 2 risk groups are almost identical.

TABLE 5
Multiple linear regression results with partial proportions of variance explained[1]

	Estimated slope[1]	SE	P	Incremental R^2
Weight at 12 mo of age				
Weight at 3 mo of age	0.824	0.123	0.0001	0.41
Maternal BMI	0.013	0.012	0.31	0.01
Male sex	0.343	0.173	0.05	0.03
Total sucks	0.0007	0.0002	0.0002	0.09
Food intake	0.003	0.007	0.0002	0.08
Total R^2	—	—	—	0.62
Weight-for-length at 12 mo of age				
Weight-for-length at 3 mo of age	0.547	0.099	0.0001	0.35
Maternal BMI	0.007	0.129	0.57	0.01
Male sex	0.400	0.0186	0.03	0.03
Total sucks	0.0007	0.0002	0.0008	0.09
Food intake	0.002	0.001	0.003	0.06
Total R^2	—	—	—	0.54

[1]The estimated slope, SE, and P values are from the model with only baseline factors included; the incremental R^2 value is from the model adding factors incrementally to the baseline model.

DISCUSSION

There were 3 major findings of this study, the first large-scale assessment of infants at high and low risk of obesity: *1*) there was no significant difference between infants at high risk or low risk of obesity in 5 measures of body size and composition at 12 mo of age: weight, weight-for-length, fat mass, fat-free mass, and skinfold thickness; *2*) energy intake predicted all of these measures at 12 mo; and *3*) energy expenditure and parental obesity predicted none of these measures.

The positive findings of this study are noteworthy. Four measures predicted a full 62% of the variance in body weight at 12 mo of age: the unmodifiable variables male sex and body weight at 3 mo and the modifiable variables energy intake and sucking behavior at 3 mo. Similar results were found for the other 4 indexes of body size and composition. The strength of these behavioral predictors is evident from the fact that they were derived from very limited information 9 mo earlier—no more than 3 d of food intake records and one test meal.

These findings go a long way to resolving the conflict among the results of the previous longitudinal studies of growth and development during the first year of life. They support the finding by Roberts (5) that the food intake of the 6 infants who became overweight was 42% greater than that of those who remained lean at 6 mo, the age at which these 6 infants first became overweight. Further support is provided by the finding of Dewey et al (6) that the greater fatness of 41 formula-fed infants than of 46 breast-fed infants was due to their greater energy intake.

Our finding that neither TEE nor sleeping energy expenditure predicted measures of body size or composition supports the results of Davies et al (2) and of Wells et al (3), who found no

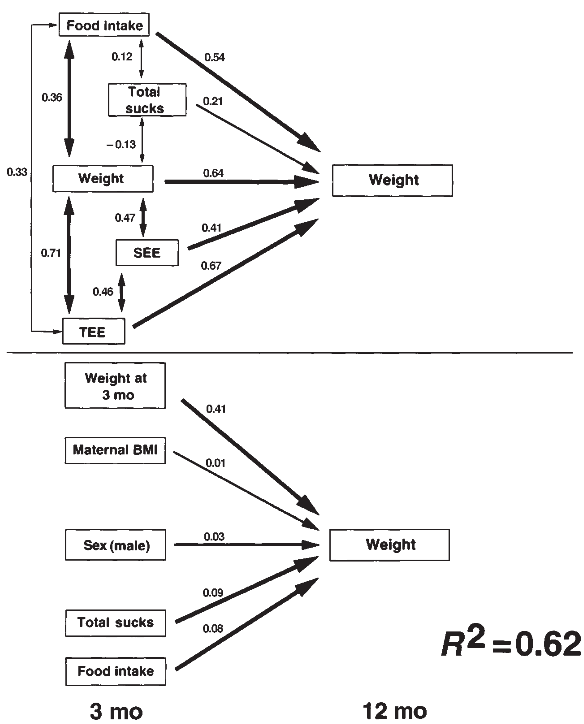

FIGURE 3. Univariate correlation coefficients among the risk factors for obesity at 3 mo of age and between those at 3 mo of age and the outcome measure of body weight at 12 mo of age (top panel) and the results of the hierarchical linear regression analysis that relates these risk factors to weight at 12 mo of age (bottom panel). Thick arrows indicate significant relations, $P \leq 0.01$. SEE, sleeping energy expenditure; TEE, total energy expenditure.

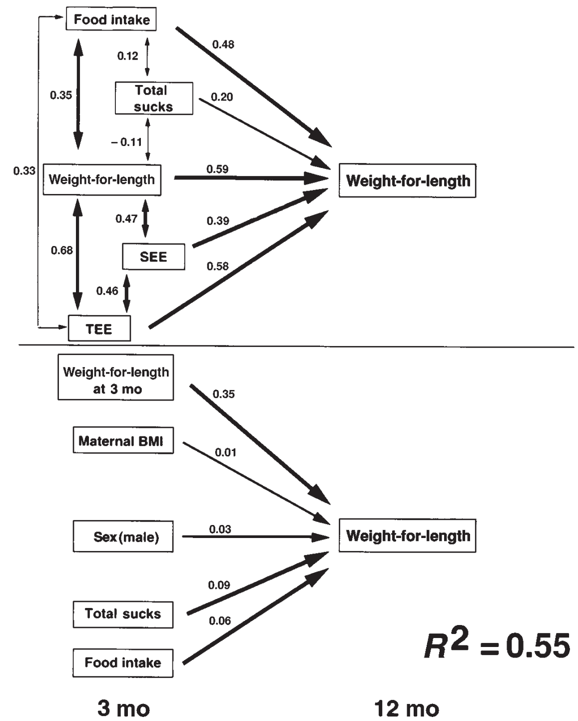

FIGURE 4. Univariate correlation coefficients among the risk factors for obesity at 3 mo of age and between those at 3 mo of age and the outcome measures of weight-for-length at 12 mo of age (top panel) and the results of the hierarchical linear regression analysis that relates these risk factors to weight-for-length at 12 mo of age (bottom panel). Thick arrows indicate significant relations, $P \leq 0.01$. SEE, sleeping energy expenditure; TEE, total energy expenditure.

relation between TEE at 3 mo and measures of body fatness at 12 mo. Our findings do not support the finding of Roberts et al (1) that a low TEE at 3 mo predicted measures of body size at 12 mo. In contrast, we found that TEE at 3 mo was highly positively correlated with body weight at 12 mo ($r = 0.71$, $P = 0.001$).

Our findings also do not support the finding of Roberts et al (1) that maternal obesity (in combination with a low TEE at 3 mo) predicted overweight in 6 infants at 12 mo. The mean BMI of our obese mothers (32.1) was almost identical to the mean BMI (32.2) of the obese mothers in the study by Roberts et al. Nevertheless, our 40 infants of obese mothers did not differ in any measure of body size or composition from the 38 infants of our nonobese mothers. We had not expected to find this lack of influence of maternal BMI on infants' weight, but a review of the literature revealed that it is not uncommon. Six studies reported no such relation during the first year of life (23–28) whereas only 2 found such a relation (29, 30).

These findings, and findings from similar studies, strongly support the view that energy intake, not energy output, is the major determinant of body size during the first year of life. Even the one exception, the findings for 6 overweight infants by Roberts et al (1), may be only apparent. Roberts et al (1) initially reported no significant difference in energy intake between low- and high-risk groups at 3 mo. However, as noted above, Roberts (5) later reported that the infants who became overweight consumed 42% more energy at 6 mo than did the infants who did not become overweight. Their having become overweight at 6 and 12 mo may have been due to their high energy intake rather than to their low TEE at 3 mo, an explanation compatible with the results of the prospective study by Ravussin et al (31) of already-obese adult Pima Indians. In this study, a reduced rate of energy expenditure predicted weight gain but less than half of the increase in body energy stores was accounted for by this reduced energy expenditure; energy intake may have accounted for the rest.

Because our results are limited to the first year of life, effects of the risk factors that we examined may differ at later ages. In fact, studies of preadolescent children have yielded conflicting results regarding the relative importance of energy intake and energy expenditure. For example, in prospective longitudinal studies, Goran et al (32) found that energy expenditure did not predict later fatness, whereas Delany et al (33) reported that reduced energy expenditure did predict increased body fat in boys. Although parental obesity has begun to exert an effect on fatness in childhood (24), it is not clear that the effect is exerted via energy expenditure. Neither Goran et al (34) nor Salbe et al (35) found a relation between parental BMI and the TEE in the children they studied, implying that a parental effect may be exerted by increased energy intake. The only prospective study of energy intake of children did not, however, support this implication: Griffiths et al (36) reported that a low energy intake at 4 y of age predicted adiposity in girls at age 15 y.

Clearly, there is a need for further studies to elucidate the respective roles of energy intake and energy expenditure in the genesis of human obesity. However, even the most careful studies face daunting obstacles. The periods of energy surplus that lead to obesity—from a high energy intake, a low energy expenditure, or both—may be transient. Accordingly, studies conducted during periods of energy balance may not detect critical relations. Furthermore, as the weights of children diverge, it becomes increasingly difficult to appropriately normalize energy intake and expenditure.

Skepticism has surrounded the accuracy of self reports of energy intake, and studies with doubly labeled water indicate that there is significant underreporting of food intake by adolescents (37) and adults (38), particularly if they are obese. The method we used to measure food intake in the present study (ie, 3-d weighed food records) involved careful weighing of the baby bottle or infant before and after each feeding over a period of 3 d; therefore, we feel that the method was reliable. Furthermore, we found no evidence of obesity-related bias: reports of infants' energy intakes by obese and nonobese mothers did not differ significantly.

Note that the 3-d food intake records were not correlated with the total number of sucks in the laboratory test meal ($r = 0.12$, $P = 0.28$). The 2 measures assess different aspects of energy intake and together provide a more comprehensive assessment than does either method alone. Furthermore, sucking behavior was the only variable that differentiated the high- and low-risk groups and, in another study, nutritive sucking behavior in infancy independently predicted adiposity in children as old as 3 y (39).

The findings of the present study suggest an alternative to a popular theory of the origin of obesity. The origin of obesity may be excessive energy intakes and not deficits in energy expenditure. This theory has implications for both research and practice, suggesting that genetic research pay particular attention to factors that control food intake. Its implications for practice and for the control of obesity are favorable: instead of being derived from largely unmodifiable metabolic determinants, obesity may result from the potentially modifiable voluntary behavior of excessive food intake.

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