Longitudinal assessment of energy balance in well-nourished, pregnant women[1–3]

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See corresponding editorial on page 583.

ABSTRACT
Background: Clinicians often recommend an additional energy intake of 1250 kJ/d to their pregnant patients. Previous studies have shown considerable variation in the metabolic response to pregnancy and thus in the additional energy required to support a pregnancy.
Objective: The purpose of this study was to assess how well-nourished women meet the energy demands of pregnancy and to identify factors that predict an individual's metabolic response.
Design: Resting metabolic rate (RMR), diet-induced thermogenesis (DIT), total energy expenditure (TEE), activity energy expenditure (AEE), energy intake (EI), and body fat mass (FM) were measured longitudinally in 10 women preconception; at 8–10, 24–26, and 34–36 wk of gestation; and 4–6 wk postpartum.
Results: Compared with preconception values, individual RMRs increased from 456 to 3389 kJ/d by late pregnancy. DIT varied from −266 to 110 kJ/meal, TEE from −105 to 3421 kJ/d, AEE from −2301 to 2929 kJ/d, EI from −259 to 2176 kJ/d, and FM from a 0.6-kg loss to a 10.6-kg gain. The only prepregnant factor that predicted FM gain was RMR (r = 0.65, P < 0.05). Women with the largest cumulative increase in RMR deposited the least FM (r = −0.64, P < 0.05).
Conclusions: Well-nourished women use different strategies to meet the energy demands of pregnancy, including reductions in DIT or AEE, increases in EI, and deposition of less FM than anticipated. The combination of strategies used by individual women is not wholly predictable from prepregnant indexes. The use of a single recommendation for increased energy intake in all pregnant women is not justified. *Am J Clin Nutr* 1999;69:697–704.

KEY WORDS Pregnancy, energy expenditure, resting metabolic rate, diet-induced thermogenesis, body composition, women, San Francisco

INTRODUCTION

The total energy cost of pregnancy can be divided into 3 parts: the obligatory need for energy deposited in the products of conception, maternal fat storage, and the extra energy needed for basal metabolism to maintain newly synthesized tissues. The estimated energy requirement during a full-term pregnancy, in excess of a woman's nonpregnant needs, is ≈335 MJ (1). Only ≈15% of this cost is attributed to the energy deposited in fetal tissues and the products of conception; the rest of the energy is accounted for by the increased rate of metabolism (≈150 MJ) and the energy deposited as fat by the mother (≈130 MJ).

Different strategies can be used to meet the additional demands for energy during pregnancy. One strategy is to increase food intake. Cross-sectional studies in well-nourished women have failed to detect increases in energy intake during pregnancy (2–4). Longitudinal studies typically show only slight increases in later stages of gestation (5–7), not enough to cover the substantial energy costs of pregnancy. A second strategy is to decrease energy expenditure during pregnancy. This can be done through a reduction in basal metabolic rate (BMR), in diet-induced thermogenesis (DIT), or in the amount of energy used for physical activity—activity energy expenditure (AEE). Studies in chronically undernourished women show that BMR declines during the first half of pregnancy, but increases by 400 kJ/d by the end of pregnancy (8, 9). Studies in well-nourished women indicate that BMR increases gradually throughout pregnancy, reaching 1213–2430 kJ/d higher than prepregnant values by the end of pregnancy (6, 10–12). Although cross-sectional studies have failed to find a reduction in energy for DIT during pregnancy (13–15), one longitudinal study found evidence for an energy-sparing adaptation amounting to a savings of 25–50 MJ over the course of pregnancy (16). A study in undernourished, pregnant women reported no change in energy for DIT (8). Studies of AEE throughout pregnancy have produced conflicting results, with reports of a decrease (17, 18), an increase (19, 20), or no change (6, 16, 21) by late pregnancy.

Finally, the energy demands of pregnancy could be met through a mobilization of fat stores, particularly in well-nour-

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ished women who begin pregnancy with sufficient energy reserves. Studies consistently show that rather than mobilizing fat stores to provide energy to the growing conceptus, however, women typically will deposit an additional 2–5 kg fat by the end of pregnancy (6, 11, 12, 22–27). Even in studies of undernourished women, fat deposition of ≈2 kg occurs (8).

It is apparent that the combination of strategies used to meet the additional need for energy during pregnancy varies with the prepregnant energy status of the woman as well as with environmental factors such as food availability and the demands of physical labor. The purpose of this study was to assess to what degree well-nourished women use these various strategies to balance their energy budget during pregnancy and to assess whether the particular combination of strategies used can be predicted from an individual's prepregnant factors.

SUBJECTS AND METHODS

Subjects

Sixteen healthy, nonsmoking women were recruited from the San Francisco Bay Area to participate in the study. Of these 16 women, 10 became pregnant within 3 mo of their preconception measurement and completed the study. Individual characteristics of the 10 subjects and their gestational outcomes are shown in Table 1. All women were classified as normal weight, with a body mass index (BMI; in kg/m^2) between 19 and 26, and were having their second or third baby. Mean (±SD) weight gain by 36 wk gestation was 11.6 ± 4.3 kg. All 10 women delivered full-term, healthy singletons with an average birth weight of 3.6 kg. Subject 8 had a cesarean delivery because of prolonged labor; the rest of the group delivered vaginally. All women breast-fed their babies through the 4–6-wk postpartum time point, except subject 4.

The study was conducted in the metabolic research unit at the Department of Nutritional Sciences, University of California at Berkeley, and at the US Department of Agriculture, Western Human Nutrition Research Center, San Francisco. The study was approved by the Human Subjects Committees of the University of California and the US Department of Agriculture. Each subject gave written, informed consent before participating.

Study design

Each woman was studied 5 times: before pregnancy (t_0); at 8–10, 24–26, and 34–36 wk gestation (t_1, t_2, and t_3, respectively); and 4–6 wk postpartum (t_{post}). Resting metabolic rate (RMR), DIT, AEE, energy intake, and body composition were assessed on each occasion. Subjects reported to the metabolic ward at the Department of Nutritional Sciences, University of California, Berkeley, on the morning of testing after a 10-h overnight fast. Subjects were instructed to consume their usual diets and to refrain from strenuous physical activity the day before testing.

Resting metabolic rate

Fasting RMR was measured between 0800 and 0830 under standard conditions after a 10-h fast by using a metabolic cart system with a ventilated canopy (Sensormedics, Inc, Yorba Linda, CA). Measurements were made every minute for 30 min while the subjects were awake but at complete rest. Energy expenditure (kJ/min) was calculated from measurements of oxygen consumption and carbon dioxide production by using the classic Weir equation (28).

Diet-induced thermogenesis

DIT was measured after subjects ate a 3135-kJ breakfast meal (75% of energy as carbohydrate, 10% as protein, and 15% as fat). Subjects were allowed 20–25 min to complete the meal, after which metabolic measurements commenced immediately. Data were collected over four 50-min periods, each followed by a 10-min break. Energy expenditure during these breaks was assumed to be the same as that in the previous 5-min interval. Minute-by-minute metabolic data were averaged into twelve 5-min increments for each of the 4 test periods. DIT was calculated from the area under the curve of energy expenditure versus time after subtracting the RMR measured on the same test day. DIT was expressed relative to the test meal size (%DIT$_{TM}$ = [DIT/test meal size (kJ) × 100].

Total energy expenditure and activity energy expenditure

TEE was estimated at each time point by using the doubly labeled water method. After the collection of baseline urine samples, subjects were given an oral dose of doubly labeled water ($^2H_2{}^{18}O$): 0.15 g $H_2{}^{18}O$ and 0.10 g $^2H_20$/kg body wt. Subjects collected midmorning spot urine samples on days 1, 5, 10, and 14

TABLE 1
Individual characteristics of the subjects and their infants

Subject	Subjects: Age	Occupation	Prepregnant BMI	Gestational weight gain	Infants: Gestational age	Sex	Birth weight
	y		*kg/m^2*	*kg*	*wk*		*kg*
1	34	Homemaker	24.1	9.5	40.7	M	3.35
2	36	Artist	23.0	11.7	40.9	F	3.07
3	23	Homemaker	21.1	13.0	41.3	M	4.45
4	31	Homemaker	24.7	8.7	41.6	F	3.86
5	29	Childcare worker	24.9	4.5	38.7	M	2.70
6	31	Salesperson	21.5	8.3	39.9	M	3.55
7	21	Receptionist	21.2	15.3	38.7	M	3.46
8	33	Homemaker	19.5	13.4	40.6	F	3.64
9	29	Diet technician	24.8	11.4	39.9	F	3.66
10	24	Homemaker	26.0	20.2	41.3	F	3.72
$\bar{x}$	29.1	—	23.1	11.6	40.3	—	3.55
SD	5.0	—	2.1	4.3	1.0	—	0.47

postdose. The urine samples were prepared for hydrogen and oxygen isotope-ratio measurements by gas-isotope-ratio mass spectrometry (29). For hydrogen isotope-ratio measurements, a 10-μL sample was reduced to hydrogen gas with 200 mg Zn reagent at 500 °C for 30 min (30). The ratios of ^{2}H to ^{1}H were measured with a Finnigan Delta-E gas-isotope-ratio mass spectrometer (Finnigan MAT, San Jose, CA). For oxygen isotope-ratio measurements, 100 μL sample was allowed to equilibrate with 300 mbar CO_2 of known ^{18}O content at 25 °C for 10 h with a VG ISOPREP-18 water-carbon dioxide equilibration system (VG Isogas, Limited, Cheshire, United Kingdom) (29). At the end of the equilibration period, the ratios of ^{18}O to ^{16}O in the carbon dioxide were measured with a VG SIRA-12 gas-isotope-ratio mass spectrometer (VG Isogas). The results are expressed in delta (δ) per mil ($^0/_{00}$) units, which are defined as follows:

$$\delta^2\mathrm{H} \text{ or } \delta^{18}\mathrm{O}\ (^0/_{00}) = (R_x/R_s - 1) \times 10^3 \qquad (1)$$

where R_x and R_s are the ratios of ^{2}H to ^{1}H or ^{18}O to ^{16}O in the sample and standard, respectively. Values of δ^2H and δ^{18}O were normalized against 2 international water standards: Vienna standard mean ocean water and standard light Antarctic precipitation (31).

The isotope-dilution spaces for ^{2}H (N_H) and ^{18}O (N_O) were calculated as follows (32):

$$N_H \text{ or } N_O \text{ (mol)} = (d \times A \times E_a)/(a \times E_d \times 18.02) \qquad (2)$$

where d is the dose of ^2H_2O or $H_2{}^{18}O$ (in g), A is the amount of laboratory water (in g) used in the dose dilution, a is the amount of ^2H_2O or $H_2{}^{18}O$ (in g) added to the laboratory water in the dose dilution, E_a is the rise in ^{2}H or ^{18}O abundance in the laboratory water after the addition of the isotopic water, and E_d is obtained from the zero-time intercepts of the decay curves for ^{2}H and ^{18}O in the urine samples.

Carbon dioxide expiration rates (rCO_2) were calculated from the fractional turnover rates of ^{2}H (k_H) and ^{18}O (k_O) and the isotope-dilution spaces as follows:

$$rCO_2 \text{ (mol/d)} = 0.4584 \times (k_O \times N_O - k_H \times N_H) \qquad (3)$$

In this equation, the in vivo isotope fractional factors 0.945 [f_1, $^2H_2O_{(liquid)} \leftrightarrow {}^2H_2O_{(gas)}$], 0.990 [$f_2$, $H_2{}^{18}O_{(liquid)} \leftrightarrow H_2{}^{18}O_{(gas)}$], and 1.039 [$f_3$, $H_2{}^{18}O_{(liquid)} + C^{16}O_{2(gas)} \leftrightarrow H_2{}^{16}O_{(liquid)} + C^{18}O_{2(gas)}$] measured at 37 °C were used (33–36). rCO_2 was converted to TEE by using the Weir equation (28) as follows:

$$\text{TEE (MJ/d)} = 0.004184 \times (3.941 \times rCO_2 + 1.106 \times rO_2 - 2.17 \times U_N) \qquad (4)$$

where rO_2 was calculated from the food quotient (FQ) (37) based on the 3-d weighed food intakes by using the relation $rO_2 = rCO_2/\text{FQ}$, and U_N is the 24-h urinary nitrogen excretion (in g). U_N values were measured by using the micro-Kjeldahl method from 24-h urine samples collected within 1 wk of each time point. Limits of error for the doubly labeled water method, including those incurred due to the anabolic state of pregnancy, were discussed elsewhere (38–40). AEE was estimated as the difference between TEE and RMR at each time point.

Energy intake

Subjects kept 3-d weighed food intake records at each time point. Records were analyzed by using NUTRITIONIST III software (version 7.2; N-Squared Computing, Salem, OR) and energy intake and macronutrient content were estimated at each time point from the 3-d average value.

Body composition

Body density was measured by densitometry after subjects voided, removed all jewelry, and changed into bathing suits. Body volume was corrected for residual lung volume, measured by oxygen dilution at the time of the densitometry measurement, with the method of Wilmore et al (41). Total body water (TBW) was measured by deuterium dilution as part of the doubly labeled water technique. TBW was estimated as deuterium space/1.04 to account for deuterium exchange with acidic body proteins. Bone mineral content was measured at t_0 and t_{post} with a dual-energy X-ray absorptiometer (Lunar DPX software version 3.6; Lunar Corp, Madison, WI).

The 4-compartment model was used to determine body composition (42). The density of fat-free mass (D_{FFM}) was calculated for each subject at each time point from the proportions of bone mineral, protein, and water comprising FFM and the component densities of each [D_{water} = 0.993 kg/L, $D_{protein}$ = 1.34 kg/L, and $D_{mineral}$ = 3.0 kg/L (43)]. Fat mass (FM) was then calculated as follows:

$$\text{FM} = W_B \times (1/D_B - 1/D_{FFM})/(1/D_{FM} \times 1/D_{FFM}) \qquad (5)$$

where W_B is body weight, D_B is density of the body, and D_{FM} was assumed to be 0.9007 (43, 44). Body protein was estimated by subtracting TBW and bone mineral content from FFM.

Statistical analysis

Longitudinal data were analyzed by univariate repeated-measures analysis of variance. If significant effects were observed, Tukey's Studentized range test at a procedure-wise error rate of 5% was used to determine which stage of pregnancy significantly affected the variables measured. Multivariate regression analyses were done to determine the individual contribution of each predictor variable to the outcome variables (FM gain and change in RMR). SAS software (version 6; SAS Institute Inc, Cary, NC) was used for all analyses.

RESULTS

Resting metabolic rate

The average increase in RMR by t_3 was 1578 ± 876 kJ/d, or 29% above the average t_0 value (Table 2). The considerable variation in individual patterns of change in RMR throughout pregnancy and in the absolute change by t_3, which varied from 456 kJ/d (subject 2) to 3389 kJ/d (subject 3), is shown in Figure 1. By t_{post}, RMRs were not significantly different from prepregnant values.

Diet-induced thermogenesis

The average DIT response to the breakfast meal was 7.2% of the energy content of the meal at t_0; this decreased to 5.7% by t_3 (Table 2). There was considerable interindividual variation in this response. The DIT response decreased from 10.5% to 2.3% of the energy content of the meal by t_3 in subject 4, whereas the DIT response of subject 1 increased from 6.4% to 9.9% of the energy content of the meal (Figure 2). By t_{post}, each woman's DIT response was similar to her t_0 value.

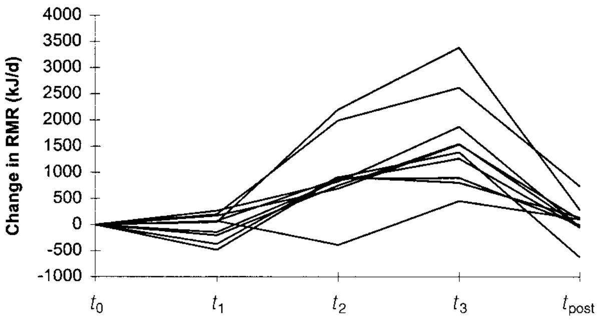

FIGURE 1. Individual changes from baseline (t_0, prepregnancy) in resting metabolic rate (RMR) throughout pregnancy: t_1, 8–10 wk gestation; t_2, 24–26 wk gestation; t_3, 34–36 wk gestation; t_{post}, 4–6 wk postpartum.

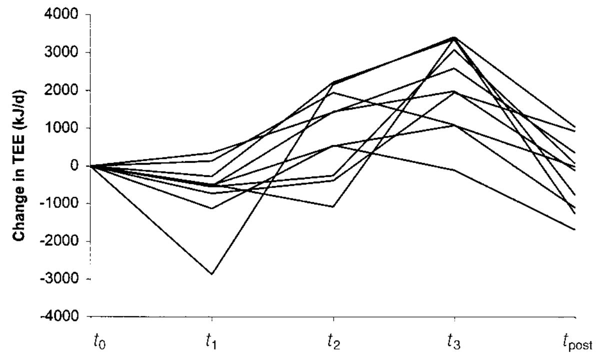

FIGURE 3. Individual changes from baseline (t_0, prepregnancy) in total energy expenditure (TEE) throughout pregnancy: t_1, 8–10 wk gestation; t_2, 24–26 wk gestation; t_3, 34–36 wk gestation; t_{post}, 4–6 wk postpartum.

Total energy expenditure

The average increase in TEE by t_3 was 2187 kJ/d, or 24% higher than the average value at t_0 (Table 2). Individual responses in TEE throughout pregnancy, which varied from a decrease of 105 kJ/d (subject 8) to an increase of 3421 kJ/d (subject 10), are shown in Figure 3. The average t_{post} value was not significantly different from the mean t_0 value.

Energy for activity

AEE increased on average by 610 kJ/d by t_3, or 23% higher than the mean t_0 value (Table 2). By t_3, individual values varied from a reduction in activity of 2301 kJ/d (subject 3) to an increase of 2929 kJ/d (subject 2). Individual patterns of change in AEE throughout pregnancy are shown in Figure 4.

Energy intakes

The 10 women increased their energy intake on average by 9%, or 775 kJ/d above t_0 values by t_3 (Table 2). All except 2 of the subjects showed increases in energy intake (Figure 5). The largest recorded increment in energy intake was in subject 3, who consumed 2176 kJ/d more than her t_0 value. The average values for energy intake at t_1, t_2, and t_{post} were all within 2% of the average t_0 value, but interindividual variation was large.

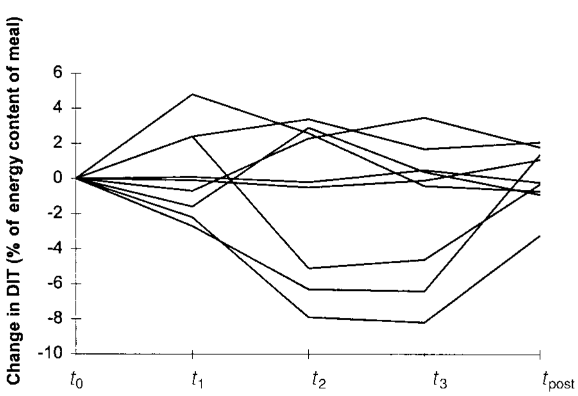

FIGURE 2. Individual changes from baseline (t_0, prepregnancy) in diet-induced thermogenesis (DIT) throughout pregnancy: t_1, 8–10 wk gestation; t_2, 24–26 wk gestation; t_3, 34–36 wk gestation; t_{post}, 4–6 wk postpartum.

Fat mass

Individual changes in FM are shown in Figure 6. The mean fat deposition by t_3 was 4.5 kg, with a range from a loss of 0.6 kg (subject 3) to a gain of 10.6 kg (subject 10). Most of the FM was deposited during the second trimester, with little change taking place in the first and third trimesters (Table 2). By postpartum, the subjects still retained an average of 2.2 kg FM over the mean t_0 value.

DISCUSSION

Previous studies have shown an immense amount of variability in the metabolic changes taking place during pregnancy (6, 11, 45), particularly cross-sectional studies. It was our hope that by conducting a longitudinal study, using each subject as her own control and making measurements before conception, we could eliminate some of this variability in the results. This was not the case. However, the longitudinal study design gave us the ability to examine the pattern of those changes taking place over the course of pregnancy and to look for relations between the changes in various components of energy expenditure and body composition in individual women. Such relations are important in examining the underlying causes for individual variability in metabolic changes. The longitudinal design, which included preconception baseline measurements, also provided us with data necessary to estimate cumulative changes in indicators of energy expenditure over the course of pregnancy. For example, a woman's RMR might decrease in the first and second trimesters of pregnancy, then increase by late gestation. This could result in a cumulative decrease in energy for RMR over the course of pregnancy—a phenomenon that occurs in undernourished women (8), which might not be detected in a cross-sectional study.

One of the objectives of this study was to determine whether any prepregnant factors could predict the changes that would take place in body composition and metabolism during pregnancy. Previous studies reported that the increase in RMR was positively related to prepregnant energy stores (8, 9, 45, 46) and to a higher energy intake during pregnancy (9). We found no relation between the increase in RMR by t_3 and any measured prepregnant factors, including body weight, BMI, FM, FFM, RMR, or energy intake. The increase was also not correlated

TABLE 2
Absolute values for RMR, DIT, AEE, EI, and FM throughout pregnancy[1]

	t_0	t_1	t_2	t_3	t_{post}	Percentage change (T3−T1)
						%
RMR (kJ/d)	5497 ± 903	5459 ± 867	6459 ± 818	7075 ± 960	5561 ± 715	29
DIT (% of energy in meal)	7.2 ± 2.9	7.5 ± 2.9	6.3 ± 2.2	5.7 ± 2.3	7.4 ± 2.6	−21
TEE (kJ/d)	9229 ± 528	8570 ± 917	10089 ± 1531	11419 ± 1282	8982 ± 1057	24
AEE (kJ/d)	3728 ± 969	3115 ± 1416	3625 ± 1174	4338 ± 1336	3417 ± 993	23
EI (kJ/d)	8569 ± 1842	8488 ± 1624	8496 ± 1654	9344 ± 2170	8367 ± 2624	9
FM (kg)	19.6 ± 4.7	19.8 ± 4.7	23.5 ± 5.0	24.1 ± 5.4	21.8 ± 4.4	23

[1] $\bar{x}$ ± SD. RMR, resting metabolic rate; DIT, diet-induced thermogenesis; TEE, total energy expenditure; AEE, activity energy expenditure; EI, energy intake; FM, fat mass. t_0, prepregnant time point; t_1, 8–10 wk gestation; t_2, 24–26 wk gestation; t_3, 34–36 wk gestation; t_{post}, 4–6 wk postpartum.

with maternal energy intake during pregnancy. It is unclear why we found no predictors of the change in RMR during pregnancy, but it is possible that the influence of prepregnancy factors and of energy intake on RMR varies among different cultural groups and among populations in whom food availability differs. The relatively small variance in prepregnant energy status (as assessed by BMI) in our group of well-nourished subjects may have also prevented us from identifying predictors of the change in RMR during pregnancy.

FM gain during pregnancy in these 10 women was not predicted from prepregnant energy intake, body weight, BMI, FM, or FFM. Goldberg et al (6) similarly found no correlation between FM gain and prepregnant weight or BMI. We found that prepregnant RMR expressed per kg FFM was positively correlated with FM gain ($r = 0.65$, $P < 0.05$), indicating that the higher a woman's RMR before pregnancy was, the more fat she would ultimately deposit. This correlation explained ≈43% of the variance in the FM deposited. The mechanism for this relation is unknown, but one could speculate that a high prepregnant RMR may be linked to a specific hormone, which might favor fat deposition during the anabolic state of pregnancy. This relation between prepregnant RMR and gestational FM deposition had not been reported previously and merits further investigation.

Cumulative changes in RMR and energy intake over the course of pregnancy were estimated from the area under each subject's curve above their preconception value. These results are summarized for each subject in Table 3. The mean incremental energy needed for RMR of 151 MJ was identical to that of Hytten and Leitch's (1) theoretical estimate of 150 MJ and fell within the range of mean values reported in other studies: 200 MJ in Sweden (20), 144 MJ in the Netherlands (10), 126 MJ in Scotland (48), and 112 MJ in England (6). Differences in mean values between these studies are likely due to the different assumptions used to extrapolate the data to 40 wk gestation as well as to the length of the intervals between RMR measurements used to calculate incremental changes in RMR.

The range of individual values in incremental RMR costs is interesting (Table 3). Although every subject's RMR had increased by t_3, RMR in subject 2 dropped by 389 kJ/d in the second trimester, resulting in a negative cumulative maintenance cost. Subject 8 also experienced an early reduction in RMR, offsetting the rise in late gestation and resulting in a lower-than-average cumulative cost. These responses are similar to those metabolic responses commonly seen in undernourished women (10, 11). Interestingly, energy intake in subject 2 dropped during pregnancy and her cumulative energy intake was the most negative of any subject, indicating a possible relation between energy intake and RMR during pregnancy. Such was not the case for subject 8, however, who had a small but positive cumulative energy intake.

In the multiple regression analysis used to examine interrelations between cumulative changes in RMR and other metabolic and body-composition changes taking place during pregnancy, we found a negative correlation between the cumulative increase

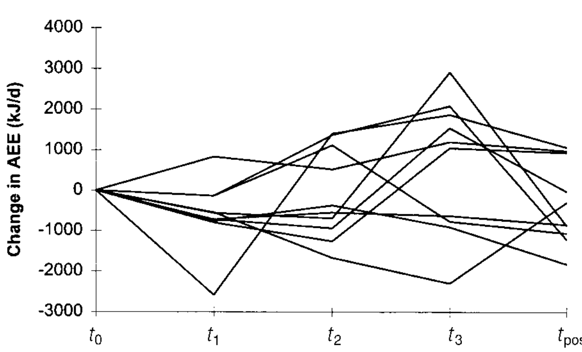

FIGURE 4. Individual changes from baseline (t_0, prepregnancy) in activity energy expenditure (AEE) throughout pregnancy: t_1, 8–10 wk gestation; t_2, 24–26 wk gestation; t_3, 34–36 wk gestation; t_{post}, 4–6 wk postpartum.

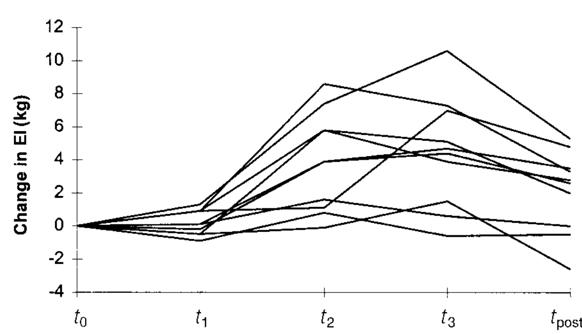

FIGURE 5. Individual changes from baseline (t_0, prepregnancy) in energy intake (EI) throughout pregnancy: t_1, 8–10 wk gestation; t_2, 24–26 wk gestation; t_3, 34–36 wk gestation; t_{post}, 4–6 wk postpartum.

TABLE 3
Individual estimates of the energy cost of pregnancy (MJ)

Subject	Tissue deposition[1] Gain in FM	Tissue deposition[1] Gain in FFM	Cumulative change in RMR[2]	Cumulative change in EI[2]	Total energy cost[3]
	MJ			*MJ*	
1	178	18	118	−17	314
2	232	25	−10	−360	247
3	−27	54	346	−278	373
4	27	43	308	0	379
5	68	12	124	67	204
6	214	8	100	97	322
7	319	38	142	333	498
8	332	46	86	71	464
9	200	28	176	235	405
10	482	33	116	42	632
$\bar{x}$	203	31	151	19	384

[1]FM, fat mass; FFM, fat-free mass; RMR, resting metabolic rate; EI, energy intake. Values of 4.6 kJ (1.1 kcal) and 45.5 kJ (10.88 kcal) (47) were used to calculate the energy cost of depositing each kilogram of FFM and FM, respectively (this allowed for both the energy content of the tissue and the cost of synthesis and deposition). These values include both maternal and fetal tissue deposition.

[2]Cumulative values for RMR and EI for the entire pregnancy were calculated from the area under the curve of each subject's values that were above their prepregnant value. If the measured value was lower than the prepregnant value, this area was subtracted from the cumulative area and considered an energy savings.

[3]Estimated from the sum of energy for FM and FFM gains and for cumulative increase in RMR.

in RMR and FM gain ($r = -0.64$, $P < 0.05$), indicating that the more a subject's RMR increased during pregnancy, the less fat she deposited. This correlation indicates that from early on in pregnancy, energy is directed primarily toward either an increase in metabolism or fat deposition. There may be physiologic advantages for one woman to increase her fat stores and for another to increase her metabolic rate. On the other hand, those women who naturally have large increases in metabolism may have less energy remaining for fat deposition. It is unknown at this point whether fat deposition drives metabolism or vice versa, or what other factors are involved in how energy expenditure is directed during pregnancy. Goldberg et al (6) found no significant association between FM gain and the cumulative changes in BMR in a group of 12 well-nourished, pregnant British women. We also observed a borderline significant correlation between the cumulative increase in RMR and FFM deposition ($r = 0.58$, $P < 0.08$), similar to the strong relation between RMR and FFM seen in nonpregnant subjects.

Finally, we looked at DIT and AEE throughout pregnancy to examine other metabolic and behavioral adjustments that might

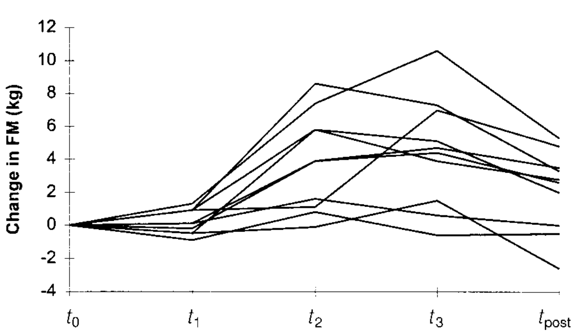

FIGURE 6. Individual changes from baseline (t_0, prepregnancy) in fat mass (FM) throughout pregnancy: t_1, 8–10 wk gestation; t_2, 24–26 wk gestation; t_3, 34–36 wk gestation; t_{post}, 4–6 wk postpartum.

be offsetting a woman's increased energy needs during pregnancy. The reductions in DIT and AEE observed could potentially account for significant energy savings if extrapolated throughout pregnancy. If summed over the last half of pregnancy, the blunted DIT effect observed in these 10 women could spare up to 29.3 MJ, similar to that seen in British women (16). The average amount of energy spared by reducing AEE in these 10 women was probably minimal, but on an individual level may have contributed to an energy savings. For example, subject 3, who had the highest prepregnant AEE of 5335 kJ/d, decreased her activity steadily throughout pregnancy, reaching a low of 3033 kJ/d by t_3. Summed over pregnancy, this reduction amounted to a savings of 294 MJ, a significant proportion of the total estimated cost of pregnancy. Subjects 4, 5, and 8 also reduced their AEE, thereby sparing ≈135 MJ over the course of pregnancy. Extremely active women or those with heavy physical workloads have the greatest potential for saving energy through a reduction in activity. Indeed, studies in Gambian women also showed reductions in AEE during pregnancy (17, 18).

The cumulative change in energy intake averaged 19 MJ, accounting for only 5% of our subjects' estimated total energy cost of pregnancy (Table 3). Individual values varied greatly. Subjects 2 and 3 had drastic reductions in their energy intake during pregnancy compared with their prepregnant values, which resulted in cumulative negative values for energy intake by term. Because each subject's prepregnant value was used as her baseline, erroneously high prepregnant measurements could account for these results. The subjects in general were compliant, motivated, and trustworthy. However, because the method was new to them at the first time point and because we used prepregnant data as baseline values, it would have been prudent to ask the subjects to repeat their prepregnant energy intake measurements or to verify the accuracy of their records by using another method.

Other studies in Western populations have similarly found little or no increase in energy intake during pregnancy (3, 48, 49). The possibility that women become more efficient and extract more energy from their food during pregnancy was refuted by de Groot et al (50). Indian women reportedly increase their intake enough to cover 96% of their estimated cost of pregnancy (15). The disparity in reported energy intakes between Western populations and Indian women could be due in part to cultural differences, given that Indian women may not feel the pressures that Western populations do to maintain their thin profile by controlling their food intake. For these reasons and because food records—even in motivated, compliant subjects—are known to underestimate true intakes (51–53), we placed more confidence in the metabolic and body-composition data than in the energy intake data.

The average total energy cost of pregnancy, estimated from the sum of the energy deposited as fat and the cumulative increase in RMR, was 384 MJ—similar to the theoretical value of 335 MJ (1) and the FAO/WHO/UNU estimate of 335 MJ (54). Individual values ranged from 204 to 632 MJ (Table 3), in agreement with ranges reported in other well-nourished women (6). The average proportion of the total energy cost contributed by FM gain and the increase in RMR, 53% and 39% respectively, were also similar to the theoretical values of 40% and 46%.

In summary, we found in a group of well-nourished women that the metabolic response to pregnancy varies widely. Women have the capacity to compensate for large increases in metabolism during pregnancy by minimizing fat deposition and possibly by reducing the energy needed for DIT and activity. Energy-sparing adaptations may play a bigger role in balancing the energy budget in populations in whom food intake is restricted, in whom the demands of physical labor are high, or in whom both conditions exist. The variability displayed in a woman's response to the energy requirements of pregnancy should be seen as a means by which the potential for a healthy gestational outcome, for both mother and infant, is optimized.

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