Energy Metabolism During Human Pregnancy

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Key Words

basal metabolic rate, energy intake, energy requirements, gestation, physical activity

Abstract

This review summarizes information regarding how human energy metabolism is affected by pregnancy, and current estimates of energy requirements during pregnancy are presented. Such estimates can be calculated using either increases in basal metabolic rate (BMR) or increases in total energy expenditure (TEE). The two modes of calculation give similar results for a complete pregnancy but different distributions of energy requirements in the three trimesters. Recent information is presented regarding the effect of pregnancy on BMR, TEE, diet-induced thermogenesis, and physical activity. The validity of energy intake (EI) data recently assessed in well-nourished pregnant women was evaluated using information regarding energy metabolism during pregnancy. The results show that underreporting of EI is common during pregnancy and indicate that additional longitudinal studies, taking the total energy budget during pregnancy into account, are needed to satisfactorily define energy requirements during the three trimesters of gestation.

Contents

INTRODUCTION

EI: energy intake

The requirement for dietary energy is the main factor affecting the amount of food a human being consumes. Therefore, the content of essential nutrients in a diet must be sufficient to cover the needs of a person consuming the amount of this diet corresponding to his or her energy needs. Furthermore, knowledge regarding energy requirements per se is important when providing dietary advice as well as in relation to the understanding of body weight regulation, an area that recently has attracted interest (4). Finally, knowledge regarding human energy metabolism is needed in relation to the increasing prevalence of obesity worldwide (38) and when evaluating the accuracy with which dietary intake can be assessed.

Extensive studies have provided a solid basis of information regarding the energy metabolism in human adults (7), whereas corresponding studies during specific periods of life, such as infancy, childhood, pregnancy, and lactation, are much less prevalent. It is a special concern that studies in pregnant women are comparatively few. Thus, the scientific basis of dietary advice currently provided to pregnant women is considerably weaker than that available to nonpregnant adults. Furthermore, we have very limited possibilities for evaluating the effects of a low or a high energy intake (EI) on the body weight and composition of pregnant women, let alone evaluating how such variations in intake affect the growing fetus. Finally, it is very difficult to evaluate the validity of dietary studies conducted in pregnant women. These limitations are serious, since nutritional factors in utero have been linked to adverse conditions later in life such as obesity (33) and cardiovascular disease (15).

An important reason for the relatively scarce information regarding energy metabolism during pregnancy concerns the difficulties involved when recruiting and investigating pregnant women. For example, to provide reliable assessments regarding the effect of pregnancy on energy metabolism and body composition, studies must be started before conception. Difficulties associated with recruiting women likely to become pregnant in the near future represent a serious problem for studies in this area. Furthermore, pregnancy is a dynamic state characterized by continuously changing conditions. No simple description regarding how pregnancy affects energy metabolism and body composition can therefore be given. Finally, these effects of pregnancy differ considerably among individual women.

ENERGY METABOLISM IN PREGNANT AND NONPREGNANT INDIVIDUALS

The concept of energy balance is fundamental to the understanding of human requirements for dietary energy (7). Thus, intake of food energy must be equal to energy expenditure corrected for any change in body energy stores. A positive energy balance represents the most common situation during pregnancy, but the energy balance of a pregnant woman may also be negative.

As shown in **Figure 1**, human energy expenditure may be divided into components, the so-called partitioning of the total energy expenditure (TEE). It is thus common to divide TEE into basal metabolic rate (BMR), diet-induced thermogenesis (DIT), and energy expended in response to physical activity or activity energy expenditure (AEE).

TEE: total energy expenditure

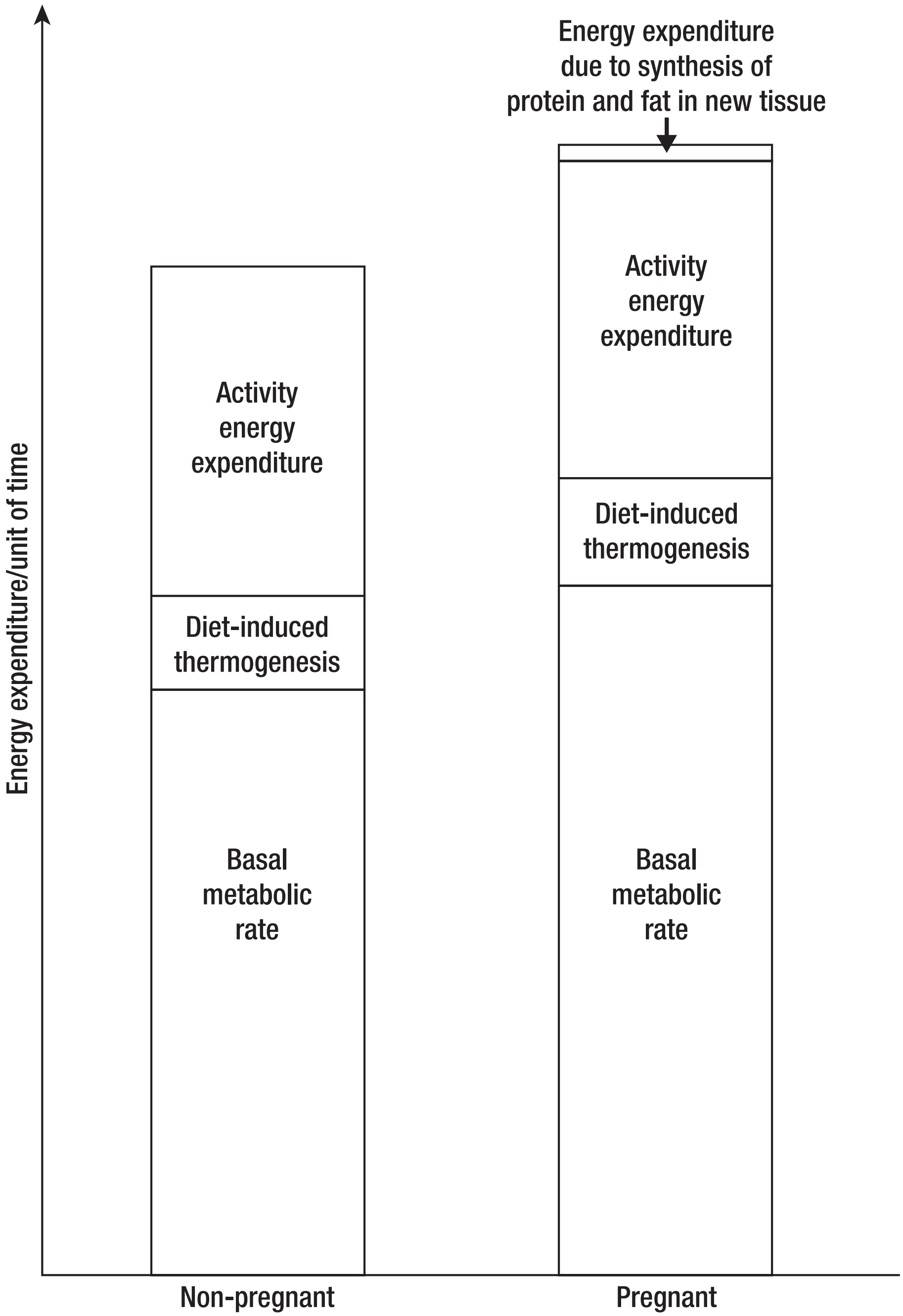

Figure 1
Partitioning of total energy expenditure in nonpregnant versus pregnant subjects.

BMR: basal metabolic rate

DIT: diet-induced thermogenesis

AEE: activity energy expenditure

RMR: resting metabolic rate

FFM: fat-free mass

PAL: physical activity level

MET: metabolic equivalent

For subjects in energy balance, TEE is the sum of these three components. The resting metabolic rate (RMR), which is slightly higher than the BMR, is often measured instead of the BMR (7). The main predictor of BMR (and RMR) is the fat-free mass (FFM) of the body; in contrast, fat mass is poorly related to BMR in healthy, nonpregnant adults (7). As indicated in **Figure 1**, BMR tends to be increased in response to pregnancy. The physiological basis for AEE is the increase in energy expenditure as the result of muscular activity (10). AEE represents the difference between TEE and BMR plus DIT but, since DIT is small, AEE is often assessed as TEE minus BMR. Another important concept is the physical activity level (PAL), which is TEE/BMR or TEE/RMR. Calculating this ratio for specific activities gives so-called MET (metabolic equivalent) values (1, 2). These can be used to calculate the TEE of a human subject over an extended period if the RMR and activity pattern of the subject are known. Prentice et al. (29) reviewed the effect of pregnancy on physical activity, AEE, and PAL and pointed out that changing energy costs of performing specific activities as well as changes in activity patterns must then be considered. Therefore, simple conclusions cannot be reached regarding how AEE is affected by pregnancy. However, PAL values obtained in pregnant women, especially during the second part of pregnancy, are not comparable with PAL values obtained in nonpregnant individuals (29). The reason is that pregnancy is often associated with a comparatively large increase in BMR, whereas the effect of pregnancy on energy expenditure when performing many specific activities tends to be rather small. Therefore, MET values tend to be lower in the pregnant than in the nonpregnant state.

In humans, energy expenditure can be augmented by stimuli other than muscular activity, such as food ingestion (7). DIT refers to the increase in energy expenditure elicited by food consumption and is generally considered to be about 10% of TEE (7, 29). Results regarding the effect of pregnancy on DIT are contradictory (29). Nevertheless, Prentice et al. (29) concluded that "it is reasonable to assume that DIT remains essentially unaltered during pregnancy when expressed as a proportion of energy intake."

The anabolic situation during pregnancy leads to a positive energy balance, with synthesis of new tissue and retention of fat and protein in the mother and in the fetus. The energy needed to synthesize new tissue containing the appropriate amounts of fat and protein consists of two components: the energy in the fat and protein actually retained in the body, and the energy needed to synthesize these compounds, the so-called energy costs of synthesis. As shown in **Figure 1**, TEE during pregnancy should be regarded as the sum of four components: BMR, DIT, AEE, and the energy costs for synthesizing the fat and protein retained.

ENERGY REQUIREMENTS DURING PREGNANCY

Butte & King (8) recently summarized the definition of energy requirements during pregnancy: "The energy requirement of a pregnant woman is the level of energy intake from food that will balance her energy expenditure when the woman has a body size and composition and level of physical activity consistent with good health, and that will allow for the maintenance of economically necessary and socially desirable physical activity. In pregnant women the energy requirement includes the energy needs associated with the deposition of tissue consistent with optimal pregnancy outcome." This definition was recently used to revise the basis for energy requirements during pregnancy (8, 13). In 1985, FAO/WHO/UNU (12) assessed energy requirements during pregnancy on the basis of a theoretical model developed by Hytten (21) with the following inherent assumptions: The prepregnant body weight of the women varied between 60 and 65 kg, the average gestational weight gain was 12.5 kg, retentions of protein and fat during the complete

Table 1 Total energy cost of pregnancy in well-nourished women calculated using two different alternatives[a] (8)

Energy costs	First trimester (kJ/24 h)	Second trimester (kJ/24 h)	Third trimester (kJ/24 h)	Total pregnancy (MJ)
Energy in retained fat and protein (a)	232	876	892	182.6
Efficiency of food energy utilization for fat and protein deposition (b)	48	134	191	34.0
Increment in basal metabolic rate (c)	249	465	1015	157.0
(b + c)	297	599	1206	191.0
Increment in total energy expenditure (d)	100	400	1500	186.0
Energy cost, alternative 1 (a + b + c)	529	1475	2097	373.6
Energy cost, alternative 2 (a + d)	332	1276	2391	368.6

[a]Calculations are based on a gestational weight gain of 13.8 kg.

gestation were 925 g and 3.8 kg, respectively, and the cumulative increase in BMR during the complete pregnancy represented an energy cost of 150 MJ (6, 8, 21). Butte & King (8) revised this model using more recently published data. They found that an average weight gain of 13.8 kg represented a useful basis for assessing energy needs during pregnancy in well-nourished women. Based on their review of the literature, they suggested that retention of 4.3 kg fat and 686 g protein as well as a cumulative increase in BMR of 157 MJ, all during a complete pregnancy, is compatible with optimal reproductive performance in well-nourished women. It is relevant to point out that for fat retention and the increase in BMR, Butte & King (8) arrived at figures in close agreement with those of Hytten (21), whereas their figure for protein retention was lower, 686 g versus 925 g (21). The model developed by Butte & King (8) forms the basis for recent recommendations regarding energy requirements during pregnancy (13). As shown in **Table 1**, these requirements were calculated using two different approaches. Both are based on the assumption that a woman retains 4.3 kg fat and 686 g protein during pregnancy. The first alternative is based on increments in BMR throughout pregnancy. The energy cost of pregnancy is calculated as the energy content in the fat and protein retained, plus the increments in BMR, plus the energy costs of synthesizing the appropriate amounts of fat and protein. The energy costs of synthesis, i.e., the efficiency of food energy utilization for protein and fat deposition, were assumed to be 90% (8). It is also assumed that AEE and DIT are not affected by pregnancy. According to this calculation, the energy cost of a complete pregnancy is 373.6 MJ. In the second alternative, calculations are based on increments in TEE obtained using the doubly labeled water (DLW)-method. This method estimates the TEE during free-living conditions (11), and such estimates will therefore include the energy costs of synthesizing the retained fat and protein as well as any changes in DIT and AEE. Consequently, the energy costs of pregnancy can be calculated as the energy content in the retained fat and protein plus the increment in TEE. Using this alternative, the total energy cost of pregnancy is 368.6 MJ. It is noteworthy that the two alternative calculations produce similar estimates for a complete pregnancy. However, the two alternatives will result in different distributions of energy costs during pregnancy. Thus, in the second approach, a larger proportion of the costs appear in late rather than in early pregnancy. This is important when assessing energy needs of women at different stages of pregnancy. It seems reasonable for such estimates to be based on assessments of TEE in agreement with corresponding estimates for other population groups. For pregnant women, however, the energy retained in the body must also be considered. The main part of this energy is due to retention of body

DLW: doubly labeled water

fat, and it is therefore relevant to note that available data on body fat retention during pregnancy (8) are of different quality for the different trimesters. The best data are available for the second trimester; these are based on several studies, all with rather similar results. Relatively few studies have focused on the first trimester, and results from different studies regarding the third trimester are quite variable.

ENERGY METABOLISM DURING PREGNANCY: RECENT INFORMATION

Basal Metabolic Rate

Butte (6) recently reviewed studies regarding the increase in BMR of well-nourished women during pregnancy. On the basis of results from 261 women in eight studies, it was found that the average cumulative increase in BMR during the complete pregnancy was 157 MJ and that average BMR increased by 4%, 10%, and 24% during the first, second, and third trimesters, respectively (6). Several authors have pointed out that the effect of pregnancy on BMR in different women often varies considerably (8). Prentice et al. (29) compiled results from developed and developing countries regarding the effect of pregnancy on BMR and demonstrated that pregnant women from developing countries increased their BMR to a much smaller extent than did women from developed countries. The increase in BMR during pregnancy may even be negative, i.e., a depression in BMR, especially during the first part of pregnancy. This probably can be attributed in part to the nutritional situation because such a depression in BMR is more common in developing than in affluent countries. However, women in developed countries may also show a depression in BMR during the first part of gestation (13). The physiological basis for this depression is incompletely understood.

Two studies (9, 25) including longitudinal measurements of BMR in well-nourished pregnant women have recently been published. In the study by Löf et al. (25), BMR in 22 healthy Swedish women was measured before, five times during, and after pregnancy. The average increments in BMR were in fair agreement with those described by Butte (6) and also confirmed that many well-nourished women (12 out of 22) decrease their BMR during the first part of gestation; in some women, this decrease persisted into the second half of pregnancy. In the study by Butte et al. (9), the BMR of women with low, normal, and high BMI values before conception was measured before and three times during pregnancy. For women with low and normal BMI values, changes in BMR during pregnancy were in agreement with those previously reported (6), whereas for women with high prepregnant BMI values, increments in BMR were larger.

The increase in BMR during pregnancy is considered to be the result of accelerated tissue synthesis, increased tissue mass, and increased cardiovascular, respiratory, and renal work (21). To understand the basis for the large variation among women in the change in BMR in response to pregnancy, specific studies of appropriate physiological changes during pregnancy are of interest. For example, Butte et al. (9) reported that during pregnancy, changes in BMR were correlated with changes in FFM but not with changes in fat mass. Bronstein et al. (5) found that BMR during pregnancy was correlated with fat mass rather than with FFM, in contrast to the situation in nonpregnant women. Löf et al. (25) observed that BMR was correlated with FFM but not with total body fat in women before pregnancy, although in the same women, significant correlations with both FFM and total body fat were obtained for BMR in gestational weeks 14 and 32. These observations may indicate an increase in the metabolic activity of adipose tissue during pregnancy.

Relatively few studies have aimed at understanding the physiological basis for a depressed BMR during pregnancy. Spanderman et al. (32) investigated circulatory changes during early pregnancy in 12 healthy women and found these changes to be unrelated to changes in BMR. It was concluded that the high-flow, low-resistance circulation that is typical for pregnancy develops independently of concomitant changes in BMR. Löf et al. (25) confirmed and extended those observations. These authors found that increases in BMR correlated with increases in cardiac output in gestational week 32 but not in gestational week 14. Other relevant observations (25) were that serum levels of free triiodothyronine decreased during pregnancy, and decreases in these levels in gestational week 32 were weakly but significantly correlated with increases in BMR. This was suggested to be of potential interest in relation to the regulation of BMR during pregnancy, since this can help to maintain an appropriate metabolic rate, perhaps by counteracting the stimulating effect on energy expenditure associated with a high body-fat content and a large fetus.

In their review from 1996, Prentice et al. (29) used mean values from nine different studies in developed and developing countries, and reported that the cumulative increase in BMR during the complete pregnancy was strongly correlated ($r = 0.75$, $p < 0.001$) with percent body fat of the women before pregnancy. This finding suggests that the nutritional status of women is important regarding the magnitude of the increase in BMR during pregnancy. This statement is supported by data (9) showing that 40% of the variability of the change in BMR during the entire pregnancy could be explained by gestational gains in weight and FFM in combination with BMI and percent body fat before pregnancy. Löf et al. (25) reported that 40% of the variability of the increase in BMR in gestational week 14 could be explained by the increase in body weight in combination with the body fat content before pregnancy. In gestational week 32, as much as 63.7% of the variability of the increase in BMR could be explained by increases in body weight in combination with fetal weight in gestational week 31. Since the increase in body weight during pregnancy and the prepregnant body fat content are both related to the woman's nutritional situation, these data support the statement that the change in BMR during pregnancy is largely a function of maternal nutritional status. However, Kopp-Hoolihan et al. (22) were unable to confirm this statement, possibly because their study had only 10 subjects with a rather small variation in prepregnancy BMI and body fat content.

Total Energy Expenditure and Activity Energy Expenditure

In 1996, Prentice et al. (29) reviewed four studies (5, 14, 18, 19) from developed countries where TEE was assessed using the DLW method in pregnant women. In the recent FAO/WHO/UNU report on human energy requirements (13), three of these (14, 18, 19) and two additional studies (9, 22) were used to calculate the effect of pregnancy on TEE in gestational weeks 30–36. The mean TEE of pregnant women was found to be 11.5 versus 9.9 MJ/24 h for nonpregnant women. When expressed as kJ/kg/24 h, a slightly lower value (160 versus 164) was found at this late stage of pregnancy in comparison with the nonpregnant state. AEE was similar for pregnant and nonpregnant women (4.3 versus 4.2) when expressed in MJ/24 h, but was lower during pregnancy (60 versus 69) when expressed as kJ/kg/24 h.

The FAO/WHO/UNU expert consultation of 1985 (12) suggested that the energy cost of pregnancy could be partly offset by reductions in physical activity. Prentice et al. (29) concluded in 1996 that "about half the energy cost of pregnancy could theoretically be spared by reductions in the physical activity of the mother. However, it is difficult to uncover any patterns that could be described as typical pregnancy-induced behavior. This emphasizes that it cannot be assumed that a high proportion of energy costs of pregnancy are normally or automatically met by reductions in activity." Butte & King (8) did not conclude that available evidence could support a

Table 2 Activity energy expenditure and physical activity level before and during pregnancy

Reference	Subjects	AEE[a] (kJ/24 h)	PAL[a]
(9)	**Low BMI[b] (n = 17)**		
	Prepregnant	3816 ± 954	1.97 ± 0.25
	Gestational week 22	3012 ± 1347	1.72 ± 0.28
	Gestational week 36	2929 ± 1866	1.63 ± 0.33[c]
	Normal BMI[d] (n = 34)		
	Prepregnant	3632 ± 1238	1.84 ± 0.25
	Gestational week 22	3535 ± 1381	1.78 ± 0.28
	Gestational week 36	3146 ± 1347	1.62 ± 0.24[c]
	High BMI[e] (n = 12)		
	Prepregnant	4778 ± 1335	1.96 ± 0.22
	Gestational week 22	3787 ± 1456	1.72 ± 0.25
	Gestational week 36	2900 ± 1682	1.49 ± 0.22[c]
(24)	**BMI 18–39[f] (n = 23)**		
	Prepregnant	5080 ± 1270	1.95 ± 0.24
	Gestational week 14	4940 ± 1070	1.89 ± 0.20
	Gestational week 32	4910 ± 1170	1.72 ± 0.17[g]
(22)	**Normal BMI[h] (n = 10)**		
	Prepregnant	3728 ± 969	–
	Gestational week 8–10	3115 ± 1416	–
	Gestational week 24–26	3625 ± 1174	–
	Gestational week 34–36	4338 ± 1336	–

[a]Values are means ± SD.
[b]BMI = 18.9 ± 0.8 kg/m^2.
[c]Significantly ($p = 0.04$) lower than the corresponding value before pregnancy.
[d]BMI = 22.1 ± 1.5 kg/m^2.
[e]BMI = 28.8 ± 2.6 kg/m^2.
[f]BMI = 24.2 ± 4.8 kg/m^2.
[g]Significantly ($p < 0.001$) lower than the corresponding value before pregnancy.
[h]BMI = 23.1 ± 2.1 kg/m^2.
AEE, activity energy expenditure; BMI, body mass index; PAL, physical activity level.

statement that reductions in physical activity could cover a significant proportion of energy needs during pregnancy, and current recommendations do not take such reductions into account (13). The three longitudinal studies (9, 22, 24) using the DLW method in well-nourished pregnant women that have been published since the review by Prentice et al. in 1996 (29) have all addressed this issue. The results, which are summarized in **Table 2**, show that pregnancy is associated with nonsignificant and quite small changes in AEE, which is in agreement with previously published data. This occurs in spite of the increase in body weight during pregnancy, an increase associated with higher costs of performing many common activities (29). Butte et al. (9) mention that where a nonsignificant decrease in AEE was observed during pregnancy, activity records confirmed a decrease in physical activity, but no data describing this decrease are presented. Kopp-Hoolihan et al. (22) did not report the physical activity patterns of their subjects. Löf & Forsum (24) studied the physical activity patterns of their 23 women using a questionnaire as well as heart-rate recording in a subgroup of 12 of these women. As shown in **Figure 2**, only minor changes in physical activity pattern were observed in gestational weeks 14 and 32 when compared with prepregnancy data. This is in agreement with the results in **Table 2** showing only small and nonsignificant changes in AEE during pregnancy for these women. However, this interpretation is only valid at the group level, and individual women may show highly variable changes in AEE during pregnancy. Data published by Kopp-Hoolihan et al. (22) indicate that there may be considerable variation among women regarding changes in AEE during pregnancy.

Table 2 also shows that in two of the three studies, PAL values decreased significantly during pregnancy. However, as previously noted, PAL values obtained in pregnant women are not comparable with PAL values obtained in nonpregnant individuals (29). The results described above demonstrate that the effect of physical activity on energy metabolism during pregnancy is complex and incompletely understood. For example, Pivarnik et al. (28) have demonstrated that regression lines relating heart rate to oxygen consumption change during pregnancy, which has implications when heart rate is used to assess energy expenditure. This indicates that alterations in the interaction between physical activity and energy expenditure may occur during pregnancy. Further evidence for such alterations was found by Löf & Forsum (24), who assessed relationships between MET values and heart rate in the same women before and during pregnancy. In the resting state (equivalent to performing an activity with a MET value of one), heart rate was 17 beats faster per minute in gestational week 32 when compared with the value before pregnancy, whereas when the women performed an activity with the MET value of 6, heart rate was the same before pregnancy and in gestational week 32. These observations may indicate that the conventional way of assessing BMR is invalid during pregnancy, when such estimates may not represent the BMR component of TEE during physical activity. In this context, it is relevant to note that BMR is usually measured during a short period assuming that the result represents the energy metabolism at complete rest during 24 hours or even several days. It is conceivable that, during pregnancy, the metabolic processes normally considered as included in BMR require less energy during physical activity than they do in the resting state. Such alterations would result in an apparently increased energetic efficiency during exercise. A possible candidate for mediating such an effect is the circulatory changes occurring during pregnancy, as mentioned above. The low-resistance circulation typical for pregnancy may influence energy costs of processes normally considered to be included in BMR measurements. It is quite conceivable that the energy costs of such processes are different for a pregnant woman when she is resting and when she is physically active. This suggestion is of course speculative, and more studies are needed on these and other aspects of interactions between physical activity and energy expenditure during pregnancy.

Diet-Induced Thermogenesis

After the review by Prentice et al. in 1996 (29), Kopp-Hoolihan et al. (22) conducted a longitudinal study of DIT in 10 pregnant women. The results demonstrate the considerable variation among women regarding the effect of pregnancy on DIT. Considering these results, it is hardly surprising that previous studies in this area have been inconclusive. The authors present their findings as part of a strategy by women to balance their energy budget during pregnancy (22).

EVALUATION OF ENERGY INTAKE IN STUDIES CONDUCTED IN PREGNANT WOMEN

Extensive studies in nonpregnant, nonlactating adults have shown that reported EI is often

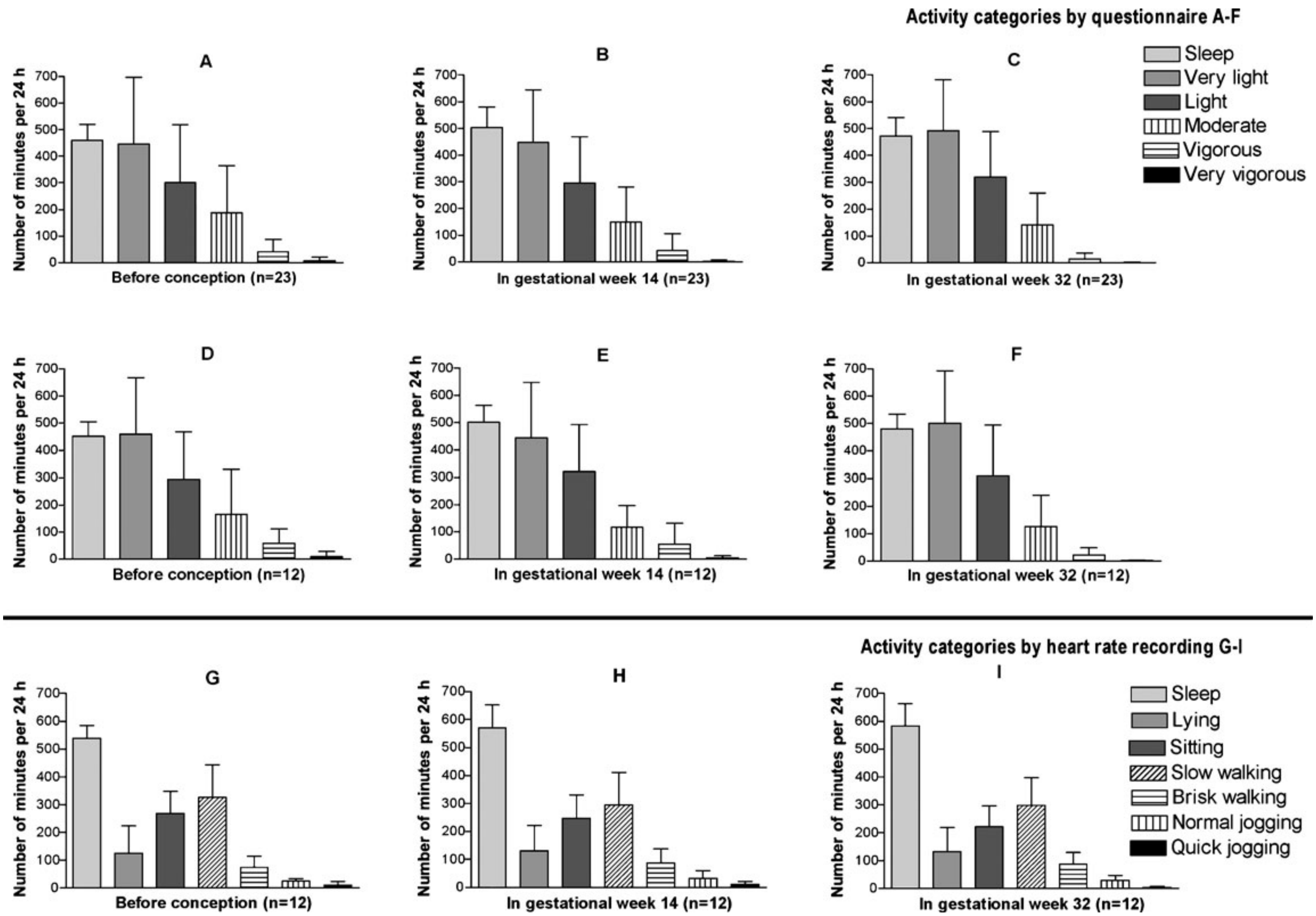

Figure 2

Pattern of physical activity assessed using a questionnaire in 23 women before pregnancy and in gestational weeks 14 and 32 (*A*, *B*, and *C*). On the same measurement occasions, physical activity pattern was also assessed using heart-rate recording in a subgroup of 12 women (*G*, *H*, and *I*). The physical activity pattern for the 12 women assessed using the questionnaire is also shown (*D*, *E*, and *F*) (24).

too low to meet physiological energy requirements (20, 35). Women, overweight individuals, and weight-conscious subjects are especially likely to underreport their EI (20). Furthermore, as pointed out by Prentice et al. (29), a substantial amount of data have been collected regarding EI during pregnancy, with results indicating that the observed increase in EI is too small to meet the energy costs of pregnancy. In 1991, Goldberg et al. (17) published a procedure by which the validity of dietary records could be evaluated. This procedure defined so-called cut-off limits for EI/BMR, thereby providing limits below which EI must be recognized as being incompatible with long-term maintenance of energy balance and survival. This kind of procedure has been widely applied to indicate the quality of dietary reports, including those of pregnant women (16, 30, 37). However, for the following reasons this procedure is not appropriate for pregnant women: First, it assumes that subjects are in energy balance, an assumption that is rarely valid during pregnancy. Second, equations to predict BMR in pregnant women are not available. Finally, there are presently no PAL or MET values for different activities that are appropriate and applicable during pregnancy.

As discussed above, information concerning the energy metabolism of pregnant women obtained by means of the DLW method has recently become available. We propose that this information can be used to formulate a procedure by which the accuracy of EI assessed in pregnant women can be evaluated; an example demonstrating such a procedure is given below. It should be pointed out that the proposed procedure has limitations due to the incomplete data on which it is based. For example, an important shortcoming is that these data are based on longitudinal studies to only a limited extent. However, the proposed procedure would be improved in stride with the further increase in the quantity and quality of available data.

We have based our example on studies reporting the EI of pregnant women that were published after the review by Prentice et al. in 1996 (29). Studies were included if they (*a*) were published on MEDLINE (**http://www.ncbi.nlm.nih.gov/entrez/query.fcgi**) before September 2006; (*b*) reported original data; (*c*) were identified by the search terms "EI" and "pregnant women" or "human pregnancy"; (*d*) were written in English; (*e*) reported an average EI, a mean body weight no later than gestational week 14, and a mean gestational weight gain of 12–14 kg and/or an average birth weight around 3.5 kg; and (*f*) were conducted in developed countries. Seven studies meeting these criteria were identified (3, 22, 26, 27, 31, 34, 36). **Table 3** describes subject characteristics, dietary assessment methods, gestational weeks when diet was assessed, prepregnancy body weight, and reported mean EI for the seven studies. The table also gives expected EI, which was calculated using data on energy metabolism obtained in healthy, well-nourished, nonpregnant women (13), as well as the data on changes in TEE and body energy stores reported for healthy, well-nourished, pregnant women shown in **Table 1**. For the studies presented in **Table 3**, we consider that average reported EI would generally equal the average expected EI.

In five of the studies in **Table 3** (26, 27, 31, 34, 36), reported EI was considerably lower than expected EI (ranging from –15% to –37%). In the study by Antal et al. (3), reported EI differed by +10%, +1%, –9%, and –12% from expected EI in gestational week 12, 20, 30, and 38, respectively. In the study by Kopp-Hoolihan et al. (22), good agreement between reported and expected EI was found in gestational week 9 (–2%), although later in pregnancy reported EI was 21% to 25% lower than expected EI.

Unfortunately, we were only able to review studies from developed countries. Available data regarding changes in energy expenditure and body composition during pregnancy for women in developing countries are much too incomplete to allow a calculation of expected

Table 3 Characteristics of studies, including reported and expected energy intake, conducted in pregnant women from developed countries

Reference	Population	Age of women	N	Dietary assessment method	EI assessed in:	Body weight before pregnancy (kg)	Reported mean EI (MJ/24 h)	Expected mean EI (MJ/24 h)[a]	Reported EI/ Expected EI
(3)	Hungarian women	26	70	Food frequency questionnaire	gw 12, gw 20, gw 30, gw 38	60.7[b]	11.16, 11.15, 10.97, 10.67	10.1, 11.0, 12.1, 12.1	1.10, 1.01, 0.91, 0.88
(36)	Dutch women[c]	28	53	Weighed food records	gw 13	65.8[d]	8.4	10.6	0.79
(31)	British women	28	11,923	Food frequency questionnaire	third trimester	61.6	7.7	12.2	0.63
(22)	American women	29	10	Weighed food records	gw 9, gw 25, gw 35	64.8	8.49, 8.50, 9.34	8.69[e], 11.4[e], 11.8[e]	0.98, 0.75, 0.79
(26)	American women[f]	25	31	Repeated 24-h recalls	third trimester	67.5	9.07	12.8[g]	0.71[h]
(27)	Australian women	29	556	Food frequency questionnaire	first trimester, third trimester	65.9	9.0[i], 9.2[i]	10.6, 12.7	0.85, 0.72
(34)	British women[f]	28	44	Weighed food records	third trimester	61.4	9.26	12.2	0.76

[a]Expected EI = prepregnant TEE plus increment in TEE for first, second, or third trimester and energy content in fat plus protein retained during first, second, and third trimesters calculated as shown in **Table 1**. Prepregnant TEE was prepregnant BMR × prepregnant PAL. BMR was calculated using maternal age and prepregnant body weight as described by FAO/WHO/UNU (13). The prepregnant PAL value was assumed to be 1.68.

[b]Body weight measured in gestational week 12.

[c]This study included two groups of women (intervention and control). The table gives results for controls only.

[d]Body weight measured in gestational week 13.

[e]Expected EI was calculated using data for TEE and body fat retention published by Kopp-Hoolihan et al. (22, 23). In addition, 35 kJ/24 h and 140 kJ/24 h were added to allow for the energy content in retained protein for the second and third trimester, respectively (8).

[f] This study included women with gestational diabetes and healthy controls. The table gives results for healthy controls only.

[g]This value is likely to be too low since the average gestational weight gain of the women was 17.2 kg; i.e., higher than 13.8, the figure for well-nourished women (8).

[h]Reported EI/expected EI is likely to be too high since expected EI is likely to be underestimated (see footnote g).

[i]Median EI.

BMR, basal metabolic rate; EI, energy intake; gw, gestational week; PAL, physical activity level; TEE, total energy expenditure.

EI as was done for well-nourished women. It is important to point out that our calculation of expected EI is based on values from the literature (8, 13). Expected EI may thus be inaccurate also for well-nourished women since it is conceivable that the women in the studies described in **Table 3** may differ from the women examined when energy requirements were established. For example, it may be argued that a prepregnant PAL value of 1.68 is too high for many women. However, using a lower PAL value (i.e., 1.55) to calculate expected EI did not affect the results in **Table 3** in any important way.

The results in **Table 3** support the general conclusion that underreporting is also common during pregnancy. However, the results of Antal et al. (3) and Kopp-Hoolihan et al. (22) showed relatively good agreement between reported and expected EI, especially during early pregnancy. One possible explanation for the results reported by Antal et al. (3) may be that in the 1990s, Hungarian women were not exposed to commercial campaigns idealizing a slender female body to the same extent as were Western women. The longitudinal studies presented in **Table 3** (3, 22, 27) may give the impression that the degree of underreporting increases with advancing pregnancy. A possible explanation could be "measurement fatigue," i.e., the subjects get tired of registering what they eat and therefore tend to record a lower food intake upon repeated reporting. However, Prentice et al. (29) found little evidence for such a phenomenon in pregnant or lactating women. If this explanation can be excluded, the results presented in **Table 3** imply that in late pregnancy, women do not generally cover their physiological energy requirements by means of diet. This can be reconciled with the common contention that in late pregnancy women have difficulty eating large amounts of food. However, it is important to point out that whether this actually is true or not requires further elucidation.

Our example in **Table 3** warrants some comments regarding the common observation that pregnant women tend to report increments in EI that are too low to meet their energy needs. It is possible that part of the reason such intake during the first part of pregnancy has appeared to be too low is because energy needs were previously based on assessments of BMR, whereas low estimate of EI towards the end of pregnancy cannot be explained in this way. It should be pointed out, however, that available information regarding the amount of energy retained in the body or mobilized from energy stores during each of the three trimesters of pregnancy is not only limited in quantity but also lacks a longitudinal aspect concerning the total energy budget during pregnancy. This may be an important consideration; for example, a woman who retains a large amount of fat during the first or second trimester may well use some mobilized fat to cover her physiological energy requirements during the last trimester. Studies considering such longitudinal aspects will be needed to obtain a satisfactory understanding of the energy requirements during pregnancy and to make it possible to evaluate the validity of EI data during pregnancy.

SUMMARY POINTS

1. The effect of pregnancy on energy metabolism varies during the course of pregnancy and differs considerably among women.
2. Energy requirements during pregnancy are calculated using increases in BMR or increases in TEE. The two modes of calculation give similar results for a complete pregnancy but result in different distributions of energy requirements during the three trimesters of pregnancy.

3. The effects of pregnancy on BMR include both stimulation and depression. A depression in BMR is also common in well-nourished women, but its physiological basis is unknown.
4. In pregnant women, MET values for defined activities are often lower than in nonpregnant subjects, especially during the second part of pregnancy. Therefore, the so-called MET system is not applicable during pregnancy.
5. Current knowledge regarding the effect of pregnancy on AEE and physical activity pattern is very incomplete and more studies are needed in this area.
6. Available evidence suggests that the efficiency of energy metabolism during physical activity may be increased during pregnancy. The mechanisms involved are unknown. We suggest that the low-resistance circulation that is typical for pregnancy plays a role in establishing this increased efficiency.
7. Recent data regarding EI during pregnancy support the conclusion that underreporting of EI is also common in pregnant women.
8. Longitudinal studies considering the total energy budget during pregnancy are needed to satisfactorily define energy requirements during the three different trimesters of gestation.

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Contents

Indexes

Errata

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