Resting metabolic rate and body composition of healthy Swedish women during pregnancy

Elisabet Forsum, PhD; Aija Sadurskis, BSc; and Jan Wager, MD

ABSTRACT Body weight, resting metabolic rate (RMR), total body potassium (TBK), and total body water were measured and total body fat (TBF) was calculated in a longitudinal study of 22 pregnant, healthy Swedish women. Measurements were made before pregnancy, at gestational weeks 16–18, 30, and 36, and 5–10 d and 6 mo postpartum. RMR increased more during pregnancy than previous estimates on well-nourished women showed and the increase was significantly correlated with the birth weight of the baby. TBK decreased during the first part of pregnancy; measurements at weeks 16–18 and 30 were significantly lower than the prepregnancy value and changes in TBK and RMR were significantly correlated. TBF gain during pregnancy was 5.8 ± 4.0 kg and 60% was already gained by gestational weeks 16–18. Gain in fat was not correlated with birth weight.

KEY WORDS Birth weight, energy requirements, pregnancy, reproduction, resting metabolic rate, total body fat, total body potassium, total body water

Introduction

Our understanding of energy requirements during normal human pregnancy is far from complete. Hytten and Leitch (1) estimated that the average well-nourished woman gaining 12.5 kg body wt during pregnancy requires 80 000 kcal in addition to her nonpregnancy energy needs. This figure includes 36 000 kcal for an increased basal metabolic rate (BMR) to cover maintenance energy requirements and 44 000 kcal for the synthesis of new tissue including 3–4 kg body fat stored in the maternal body. Although it seems likely that these figures are fairly realistic averages in healthy, well-nourished women little is known about variations among individuals. A successful outcome to pregnancy can occur within a large range of changes in body weight but little is known about the nature and quality of the materials stored. This was pointed out by Thomson (2), who suggested that investigations should be directed at the nature and meaning of these variations. Furthermore, considerable uncertainty exists regarding the true changes in body weight, body composition, and resting metabolic rate (RMR) during early pregnancy because most studies have started at the 10th week of gestation or later.

It appears that successful reproduction in malnourished women can occur on dietary intakes much below those suggested by the data of Hytten and Leitch (1) although such situations clearly are suboptimal for several reasons, including low average birth weight, increased frequency of low-birth-weight infants, and increased frequency of perinatal deaths. Powerful mechanisms apparently exist that, for the benefit of reproduction, conserve energy during pregnancy. This was demonstrated by Lawrence et al (3), who measured RMR of unsupplemented and supplemented malnourished Gambian women. They found that the cumulative energy costs of increased maintenance metabolism were only 1000 kcal for the unsupplemented and 13 000 kcal for the supplemented women. In a preliminary report (4) we showed that the corresponding figure for well-nourished Swedish women is ~46 000 kcal, a figure considerably above earlier estimates for well-nourished populations of women.

It appears that the change in metabolic rate caused by pregnancy varies considerably among populations with different nutritional status. Consequently, additional data collected on well-nourished and malnourished women with respect to variables of interest for undernutrition.
standing nutritional requirements during pregnancy are needed as a basis for establishing adequate dietary guidelines during pregnancy. Such studies may also help to define an optimal level of nutrition during reproduction and to understand the energy-conserving mechanisms apparently operating during pregnancy.

This study was designed to measure longitudinal changes in RMR and body composition in healthy Swedish women starting before conception and ending 6 mo after delivery.

Subjects and methods

Enrollment of subjects

In Sweden birth control is to a large extent provided at maternity health centers by midwives authorized to apply and remove intrauterine devices (IUDs) and prescribe oral contraceptives. We arranged with midwives at Huddinge University Hospital's maternity health centers to ask each woman wishing to remove her IUD to become pregnant to consider participating in a study of nutrition during pregnancy and lactation. If interested, the woman was given details of the study and was invited to participate. Seventy-seven women received this information and agreed to participate. Four of them did not become pregnant during the study and seven left the study for other reasons. Thus, 22 women completed the study. As soon as possible after enrollment the pre pregnancy measurements were made and the IUD was removed.

Subjects

Women were recruited from a middle-income population of Swedish citizens. All were married, had completed ≥ 9 y of compulsory schooling, and had some kind of professional education. At the time of enrollment they were all professionally active (eg, in nursing, teaching, or clerical work). Four of the women had two children, one had none, and the remaining 17 each had one child. A compilation of anthropometric, dietary, obstetric, and general data about the 22 study participants is shown in Table 1. They were all healthy, all had normal pregnancies, and all but one delivered vaginally. All started breast-feeding in the hospital and 6 mo postpartum 12 of them were still partially breast-feeding. Some of the data obtained for 17 of these women were reported in a study of energy metabolism during human lactation (5).

Table 1

<table>
<thead>
<tr>
<th>Characteristics of study participants*</th>
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<tbody>
<tr>
<td>Prepregnancy body weight (kg)</td>
<td>61.0 ± 9.9</td>
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<tr>
<td>Height (cm)</td>
<td>165 ± 5</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>22.3 ± 3.5</td>
</tr>
<tr>
<td>Prepregnancy energy intake (kcal/d)</td>
<td>1900 ± 400</td>
</tr>
<tr>
<td>Prepregnancy protein intake (g/d)</td>
<td>68 ± 15</td>
</tr>
<tr>
<td>Total weight gain during pregnancy (kg)</td>
<td>13.6 ± 3.0</td>
</tr>
<tr>
<td>Length of gestation (d)</td>
<td>275 ± 14</td>
</tr>
<tr>
<td>Birth weight of baby (g)</td>
<td>3560 ± 443</td>
</tr>
<tr>
<td>Age at prepregnancy measurement (y)</td>
<td>28.7 ± 4.0</td>
</tr>
<tr>
<td>Time between prepregnancy measurement and start of pregnancy (wk)</td>
<td>14.2 ± 9.3</td>
</tr>
</tbody>
</table>

* x ± SD; n = 22.

Protocol

Measurements were made of each woman at six times: before pregnancy, three times during pregnancy (16th–18th gestational week, 30th gestational week, 36th gestational week), and 5–10 d and 6 mo postpartum. The gestational week was estimated from ultrasound measurements taken in week 16. Measurements of body weight, body composition, and RMR were carried out on each occasion. Food intake was measured before pregnancy. At each measurement the woman arrived by taxi at the hospital, ~0700. She was instructed not to have breakfast (but had not necessarily been fasting for 12 h) and to do as little as possible on the morning of testing. First, she was given a dose of 18O-labeled water to drink for estimating total body water (TBW) and then she rested for 45–60 min before RMR and total body potassium (TBK) were estimated. The protocol of this study was approved by the ethical committee of the Karolinska Institute, Stockholm, Sweden.

Maternal body weight

Maternal body weight (MBW) of women in light underwear was estimated with a Statham mechanical balance (AB Statham, Jönköping, Sweden) to the nearest 0.1 kg. The same balance was used throughout the study. The women were also weighed in the delivery room before delivery and the difference between this value and the prepregnancy body weight was considered to be the total weight gained during pregnancy.

Total body water

Total body water (TBW) was estimated as described by Schoeller et al (6). The appropriate amount of 18O-labeled water (YEDA Stable Isotopes, Rehovot, Israel), 10 atomic percent (100 g/L) was weighed out. The subjects received 1 g/kg body wt of this water at all measurements except the last pregnancy measurement and the first measurement postpartum, when 0.4 g water/kg body wt was given. Baseline saliva and urine samples were collected before the dose was given and after 4 h another saliva sample was taken. Two to six morning urine samples were also collected from each subject during a period of ~2 wk after the dose was taken. 18O in saliva and urine was analyzed with a mass spectrometer (Sira 9, VG Isogas, Manchester, Great Britain) and body water was calculated from saliva samples collected before and 4 h after dosing. In 14 cases these values were also checked by analyzing urine samples and extrapolating to time zero assuming single-pool kinetics (7).

Total body potassium

TBK was estimated in a whole-body counter (8) calibrated with a phantom containing KCl and corrections were made for different weights and heights of the subjects. A counting time of 2000 s was used for the patients and background, giving an overall methodological error of 7–8% (9). TBK of two healthy subjects who had little variation in body weight were found to be within the expected range throughout the course of the study.

Total body fat

Total body fat (TFB) was calculated with the model described by Pipe et al (10), which is based on estimates of MBW, TBK, and TBW. During pregnancy this model deducts the contributions of weight, water, and K of the fetus and its adnexa, thus making the calculation of TFB in the maternal body possible.
Resting metabolic rate

RMR was estimated by collecting the expired air during two periods of 8–12 min in Douglas bags (Börge Hansen, Köpenhamn, Sweden). Duplicate analyses of oxygen and carbon dioxide were made according to Scholander (11). Energy metabolism was calculated according to Brouwer (12). The increase over the prepregnant value in RMR was calculated for each subject for each measurement and plotted against the gestational time. To calculate the cumulative increase in RMR, the area under the curve from the start of pregnancy until delivery was estimated.

Energy and protein intakes

These values were calculated from a record kept by each woman during four consecutive days, including a Saturday or Sunday, that were typical of her life. The subject was supplied with a balance that weighed to the nearest gram and given written and oral instructions on how to weigh all foods and measure all drinks consumed. The representativeness of the food habits during these days for each woman was checked by a 1–2-h personal interview about her food habits. The energy and protein contents of the foods recorded were calculated using Swedish food tables (13).

Statistical analyses

Statistical treatment of the data (regression analysis and t test of paired observations) was performed with conventional methods (14).

Results

MBW, TBW, TBK, TBF, and RMR measurements before and during pregnancy as well as postpartum are shown in Table 2. Although these women increased their body weights during early pregnancy their TBK decreased significantly. Also, 6 mo postpartum TBK was significantly lower although MBW was slightly higher compared with the prepregnant value. Similarly, TBW showed a tendency to decrease during early pregnancy and was also significantly lower 6 mo after pregnancy than before. Calculated figures for body fat show that these women contained significantly more fat at all measurements during and after pregnancy than before. By the first measurement during pregnancy the women had gained an average of 3.5 kg body fat (range, -1.1–9.8 kg), constituting on average about 60% of the total fat gain during pregnancy. On average these women gained 5.8 kg body fat during the complete pregnancy (range, -2.6–12 kg) and 6 mo postpartum they still possessed an average of 3.2 kg (range, -5.2–10 kg) more body fat than before pregnancy. This last figure should be compared with an average remaining weight gain of <1 kg 6 mo postpartum.

Table 2 also shows that RMR increased throughout pregnancy; the average figure in week 36 was 130% of the prepregnancy value. RMR expressed as percent of the corresponding prepregnant value showed a high standard deviation at all measurement times, which indicates that the response of an individual woman could be very different from the average presented in the table.

The mean values (±SD) of the cumulative increase in RMR and birth weight of the baby (BBW) are shown in Table 3. (For regression analysis RMR [in kilocalories] was x and BBW [in grams] was y.) The complete increase in RMR during pregnancy for this group of women (50 300 kcal) had a very large SD (37 400 kcal). The increased metabolic rate during the second half of pregnancy was responsible for most (80%) of the total increase. Regression analysis showed that the cumulative

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**TABLE 2**

Maternal body weight (MBW), total body water (TBW), total body potassium (TBK), total body fat (TBF), and resting metabolic rate (RMR) in healthy Swedish women before, during, and after pregnancy*

<table>
<thead>
<tr>
<th></th>
<th>MBW</th>
<th>%</th>
<th>TBW</th>
<th>%</th>
<th>TBK</th>
<th>%</th>
<th>TBF</th>
<th>%</th>
<th>RMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepregnancy</td>
<td>61.0±9.9</td>
<td>—</td>
<td>33.0±4.3</td>
<td>—</td>
<td>2397±327</td>
<td>—</td>
<td>17.2±6.9</td>
<td>—</td>
<td>0.936±0.124</td>
</tr>
<tr>
<td>Gestational weeks</td>
<td>6-18</td>
<td>63.7±9.7†</td>
<td>104.7±3.6</td>
<td>32.5±3.7</td>
<td>99.1±8.5</td>
<td>2224±298‡</td>
<td>93.5±11.6</td>
<td>20.7±6.0†</td>
<td>128.3±28.7</td>
</tr>
<tr>
<td>Gestational week 30</td>
<td>70.2±9.9†</td>
<td>115.6±4.6</td>
<td>36.7±3.7†</td>
<td>112.3±11.6</td>
<td>2290±330‡</td>
<td>95.8±9.0</td>
<td>22.6±6.9†</td>
<td>141.3±39.5</td>
<td>1.147±0.143‡</td>
</tr>
<tr>
<td>Gestational week 36</td>
<td>72.7±10.3†</td>
<td>119.8±5.1</td>
<td>38.7±4.4†</td>
<td>118.4±13.3</td>
<td>2507±307</td>
<td>105.8±14.4</td>
<td>22.3±7.1†</td>
<td>139.2±39.6</td>
<td>1.223±0.124‡</td>
</tr>
<tr>
<td>5–10 d postpartum</td>
<td>67.6±10.8†</td>
<td>111.1±5.7</td>
<td>34.2±3.7†</td>
<td>104.3±12.9§</td>
<td>2366±294§</td>
<td>99.0±10.8§</td>
<td>22.9±7.8§</td>
<td>142.9±40.8§</td>
<td>1.063±0.169§</td>
</tr>
<tr>
<td>6 mo postpartum</td>
<td>61.9±10.9§</td>
<td>101.7±5.8§</td>
<td>31.4±4.0§</td>
<td>95.6±7.3§</td>
<td>2240±252§</td>
<td>95.1±8.3§</td>
<td>20.4±7.9§</td>
<td>123.2±28.9§</td>
<td>0.984±0.103§</td>
</tr>
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</table>

* X±SD. n = 22 except where otherwise indicated. † % = percent of value obtained before pregnancy. ‡ Significantly different from prepregnancy value (p < 0.001). § Significantly different from prepregnancy value (0.05 < p < 0.01). †† n = 21. ‡‡ n = 20.
increase in RMR during the second half of pregnancy and during the complete pregnancy correlated significantly with BBW whereas no such significant correlation was found in the first half of pregnancy. The total cumulative increase in RMR during pregnancy was not correlated with nutritional status, expressed as body mass index or percent body fat, or with energy intake of the mother before pregnancy.

To investigate possible correlations between changes in RMR, TBK, MBW, TBF, and TBW, regression analyses were performed at each measurement between all possible combinations of the above variables. In these calculations the figures used were always expressed as percent of the value obtained at the prepregnancy measurement. Some of the correlations considered to be of interest are given in Table 4. In addition, regression analysis between changes in the variables mentioned above and BBW and, for TPK, BBW in relation to the maternal height (BBW:MH) were performed; significant correlations are shown in Table 4.

Confirming findings presented in Table 3, the relationship between the increased RMR and BBW appeared to be related to events occurring during the second half of pregnancy because significant correlations between these variables were obtained at gestational weeks 30 and 36 but not at weeks 16–18. Note that the changes in TBK and RMR were correlated at the second measurement during pregnancy but not at the other measurements. The changes in TBK were not significantly correlated with changes in MBW, TBW, or TBF or with BBW at any of the measurements. However, at the first measurement during pregnancy the correlation between the change in TPK and BBW in relation to MH (BBW:MH) was significant. Changes in MBW were significantly correlated with changes in TBW 5–10 d postpartum and with changes in TBF 6 mo postpartum. A significant correlation, not shown in the table, was found between changes in MBW and RMR 6 mo postpartum. Except for the relationship between MBW and TBF shown in the table, changes in TBF were not significantly correlated with changes in MBW, TBP, RMR, or BBW for any of the measurements. Correlations between changes in TBW and TBF at all measurements were significant but the results are not shown in Table 4.

Discussion

The kind of study reported in this paper cannot be carried out on a truly random sample of the population. Thus, it becomes important to consider how representative our women are for Swedish women in general. The average increase in weight during pregnancy and the average birth weight of the babies of our subjects are very similar to corresponding figures compiled from a population of 444 women at Huddinge University Hospital during recent years, suggesting that it is reasonable to regard our group of women as fairly representative of the population.

The results of this study differ in several respects from...
results obtained in similar studies of well-nourished pregnant women. For example, in studies on Scottish (15) and Dutch (16) women the amount of fat gained during pregnancy was found to be considerably smaller than the figure obtained in our study. This could of course indicate a true difference but at least part of the difference could be due to many of the Dutch and Scottish women being examined for the first time around week 10 of pregnancy. According to our study a considerable amount of fat is retained early in pregnancy and it is thus possible that a significant part of the retained fat is present already at week 10 of pregnancy. Another possible reason for the different results is that different techniques for the estimation of body fat were used. In the Scottish and Dutch studies underwater weighing and skinfold measurements were used.

We used a model developed by Pipe et al (10) for calculating TBF in the maternal body. We chose this model because it is based on measurements of TBK, TBW, and MBW. The results of our K measurements were somewhat unexpected and suggest that some of the fundamental assumptions made in the model may not be valid. However, estimates of body fat based on measurements of body water and body weight only (17) correlated well with estimates based on the model given by Pipe et al (10) (r varied between 0.98 and 0.99 at the different measurements). The construction of the model is such that when the body weight of the subject increases and the body water decreases, which was the situation for several subjects at the first pregnancy measurement, the increase in body fat will be larger than the increase in body weight. According to current concepts such changes occur when the composition of the body changes, i.e., when the concentration of fat in the body increases. However, these concepts are based on an assumption about the water content of the fat-free body that is not necessarily valid during pregnancy and postpartum. Our results of body fat estimations should thus be considered somewhat tentative and they need to be compared with other independent methods for body-fat estimations. We find this especially important because in our study increases in body weight correlated poorly with increases in body fat.

The values for TBW reported in this paper are based on the analysis of $^{18}$O in saliva samples obtained before and 4 h after dosing. However, for 14 measurements (three prepartum, five during pregnancy, and six postpartum) the urine samples collected were also analyzed and the $^{18}$O enrichment of urine at time zero was calculated with single-pool kinetics (7). The difference between the $^{18}$O enrichment in saliva and urine varied from 0 to 3% of the enrichment of saliva. Based on these results we considered analyses of saliva samples before and 4 h after dosing appropriate for estimating TBW during pregnancy and postpartum.

The finding that TBK decreased significantly during the first part of pregnancy was unexpected. Pipe et al (10) also examined TBK in pregnant women serially but, because prepregnancy measurements were not included, a decrease due to pregnancy could not be demonstrated. The unexpected results with respect to TBK obtained in this study raise some important questions about whole-body counting. Our calibration procedure took into account that subjects have different heights and weights but apart from that no special attempts were made to correct for the changes in body shape occurring during pregnancy. It is possible that a changing geometry during pregnancy influenced our results although it seems unlikely that such effects could have been very important in the beginning of pregnancy or after delivery. Another factor that could be important was the increased amount of subcutaneous fat retained by the women, which might have attenuated the radiation from K in the cells.

Our findings of a decrease in TBK during the first part of pregnancy and 6 mo postpartum need to be confirmed in other studies because of the uncertainties mentioned above. In nonpregnant adults a decrease in lean body mass would be the obvious interpretation of such findings and it is possible that this is at least part of the explanation because TBW showed a tendency to decrease in the beginning of pregnancy and 6 mo postpartum. However, changes in TBK and TBW were not correlated, indicating that some other factor (or factors) is responsible for the decrease in TBK. In a recent paper Cheek et al (18) reported that muscle samples from pregnant women contained less intracellular K and water than those from nonpregnant women, a finding that supports our results. Our finding that the change in TBK was related to the change in energy metabolism during the first part of pregnancy supports the idea that the change in TBK is the result of some physiological event. A possible hypothesis to explain our findings is that the activity of the sodium-potassium pump, which is often assumed to make up a considerable part of the resting metabolism, may vary in response to the demands of pregnancy on the energy metabolism of the woman. Data in support of this hypothesis were presented recently (19) although different opinions appear to exist regarding the potential of the Na-K pump for saving energy (20, 21). Another possibility is that the decreased K content is related to the well-known changes in water and electrolyte balances during pregnancy. Fearal et al (22) studied the variability in water and electrolyte contents in human skeletal muscle and their results indicate that the contents of Na and K in this organ are variable and strongly negatively correlated. Finally, however, the K content of the different organs of rat dams was not affected by pregnancy except in the case of the skeleton, where a significant decrease was found (23).

An interesting result of this study is that the cumulative increase in RMR correlated with BBW and that this relationship appears to be a feature of the second half of pregnancy. This fits well with results from Gambian women (3) who increased their RMR and gave birth to heavier babies after energy supplementation during pregnancy. Our study, in agreement with earlier findings (24), does not substantiate any relationship between maternal energy stores and BBW, although a relationship
was found between BBW:MH and the change of maternal body K in the beginning of pregnancy. This is in agreement with a suggestion by Briend (25) that a factor associated with maternal lean body mass rather than with maternal energy stores is involved in the regulation of BBW. This raises the question of the significance of maternal energy stores and their regulation.

The women in this study gained more weight and body fat, delivered heavier babies, and increased their RMR more during pregnancy than the figures by Hytten and Leitch (1) suggest as the average for well-nourished populations of women. However, it is not possible to conclude that either of these two sets of figures is more representative of an optimal nutritional situation than the other. Also, all estimates related to energy requirements show large SDs, which demonstrates the difficulties in defining a reference woman on whom the estimates of energy requirements during pregnancy could be based. We are apparently far from being able to estimate energy requirements during human reproduction.

We thank all the women who participated in this study for their devoted cooperation. We also wish to express our gratitude to Professors B Pernow and L Kaiser at the Department of Clinical Physiology, Karolinska Hospital, for help with measurements of RMR and to Dr P Reizenstein and Ms M Ekman for help with measurements of TBK. Ms I Nilsson, Ms M Thilén, and Ms B Häggkvist are gratefully acknowledged for skillful technical assistance. We thank Dr F Westman for his help with isotope analyses.

References