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Variations in resting energy expenditure: impact on gestational weight gain

EK BERGGREN, MD¹, P O'TIERNEY-GINN, PhD¹, S LEWIS², L PRESLEY, BA¹, S HAUGUEL DE-MOUZON, PhD¹, and PM CATALANO, MD¹

¹Case Western Reserve University/MetroHealth Medical Center, Center for Reproductive Health, Department of Reproductive Biology

²Center for Health Care Research and Policy, Case Western Reserve University at MetroHealth Medical Center, Cleveland, OH

Abstract

Background—There are significant variations in gestational weight gain with many women gaining in excess of Institute of Medicine guidelines. Unfortunately, efforts to improve appropriate gestational weight gain have had only limited success. To date, interventions have focused primarily on decreasing energy intake and/or increasing physical activity. Maternal resting energy expenditure, which comprises ~60% of total energy expenditure compared with the ~20% that comes from physical activity, may be an important consideration in understanding variations in gestational weight gain.

Objective—Our objective was to quantify the changes in resting energy expenditure during pregnancy and their relationship to gestational weight gain and body composition changes among healthy women. We hypothesized that greater gestational weight gain, and fat mass accrual in particular, are inversely related to variations in resting energy expenditure.

Study design—We conducted a secondary analysis of a prospective cohort studied preconception and late (34–36 weeks) pregnancy. Body composition (estimated using air densitometry, BodPod) and resting energy expenditure (estimated using indirect calorimetry) were measured. The relationship between changes in resting energy expenditure and gestational weight gain, and change in fat mass and fat free mass were quantified. Resting energy expenditure was expressed as kilocalories per kilogram of fat free mass per day (kcal.kg FFM⁻¹.day⁻¹) and kilocalories per day (kcal/day). Correlations are reported as *r*.

Corresponding author: Patrick M Catalano, MD, Case Western Reserve University at MetroHealth Medical Center, Center for Reproductive Health, Department of Reproductive Biology, 2500 MetroHealth Drive Cleveland, OH 44109, phone: 216 778 4262; fax: 216 778 4691, pcatalano@metrohealth.org.

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Results—Among 51 women, preconception body mass index was 23.0 (4.7) kg/m²; gestational weight gain was 12.8 (4.7) kg. Preconception and late pregnancy resting energy expenditure (kcal/day) correlated positively with the change in fat free mass ($r=0.37$, $p=0.008$; $r=0.51$, $p=0.001$). Late pregnancy resting energy expenditure (kcal.kg FFM⁻¹.day⁻¹) was inversely associated with the change in fat mass ($r=-0.34$, $p=0.02$) and gestational weight gain ($r=-0.29$, $p=0.04$). From pre-pregnancy through late gestation, the increase in resting energy expenditure (kcal/day) correlated positively with the change in fat free mass ($r=0.44$, $p=0.002$), and negatively with the change in fat mass ($r=-0.27$, $p=0.06$).

Conclusions—The change in resting energy expenditure from preconception through late gestation correlated positively with changes in fat free mass but negatively with fat mass accrual. Women with smaller increases in resting energy expenditure across pregnancy had greater gestational weight gain, specifically more adipose tissue. These data suggest that resting energy expenditure is an important factor in gestational weight gain, particularly excess fat mass accrual. Future lifestyle intervention studies need to consider clinically feasible means of estimating resting energy expenditure and, in response, tailor nutrient intake and composition recommendations. Implementing and testing such interventions would be a novel approach to improve compliance with gestational weight gain guidelines.

Keywords

body composition; fat mass; gestational weight gain; indirect calorimetry; resting energy expenditure; maternal fat mass; pregnancy

Introduction

There are wide variations in gestational weight gain in pregnancy. Currently, over half of U.S. women exceed the 2009 Institute of Medicine Guidelines.^{1, 2} Excess gestational weight gain is associated with adverse short and long-term maternal and neonatal morbidity, especially among normal-weight women.^{1, 3, 4} The prevailing assumption is that variations in gestational weight gain relate primarily to excess in energy intake and/or decreases in physical activity. Therefore, in order to improve compliance with the Institute of Medicine Guidelines, as shown in Table 1, multiple lifestyle intervention trials employing various diets and increasing physical activity have been conducted.^{5–7} Unfortunately, to date, lifestyle intervention trials have had limited success at mitigating excess gestational weight gain or significantly improving maternal or neonatal outcomes.⁵

An important concept in energy balance is that total energy expenditure is composed not only of physical activity (~20%), but primarily of resting energy expenditure or basal metabolic rate, accounting for approximately 60% of total energy expenditure.⁸ The remainder includes the energy required to digest and absorbing food (dietary induced thermogenesis) and facultative thermogenesis, i.e. responses to environmental changes in temperature.⁸ Worldwide, there are wide variations in change in total energy expenditure over the course of pregnancy. Estimates of total energy expenditure range from a net savings of 24,000 kcals in women who did not have nutrient supplementation during pregnancy in the Republic of the Gambia⁹ to a net cost of over 60,000 kcals in a European population¹⁰ as well as wide variations within populations.⁹

Given its substantial contribution to total energy expenditure, maternal resting energy expenditure may be an important consideration in understanding variations in gestational weight gain. Thus, the aim of this research was to determine the changes in resting energy expenditure during pregnancy and the relationship to gestational weight gain and body composition in healthy women. We hypothesized that increases gestational weight gain and fat mass in particular are inversely relate to variations in resting energy expenditure.

Materials and Methods

Study Design

This was a secondary analysis of a prospective observational cohort of women who were recruited before a planned pregnancy. The objective of the primary study was to examine the prospective longitudinal changes in maternal carbohydrate metabolism, body composition, and energy expenditure in women with normal glucose tolerance and women developing gestational diabetes. Study procedures preconception and late pregnancy were part of a larger research protocol, as has been described elsewhere.^{10, 11}

The primary study procedures were conducted during two outpatient visits at Medical Center Hospital of Vermont from 1985–1991 and MetroHealthMedical Center, Cleveland, OH, from 1990–1998.^{10, 11} Study visits to the clinical research units were performed at approximately 3 months preconception (median 3, interquartile range [1–7] months) during the follicular phase of the menstrual cycle and in late (33 0/7 – 36 6/7 weeks) pregnancy. The research protocol was approved by the respective Institutional Review Boards and written informed consent was obtained from each participant.

Study Cohort

Healthy women recruited for the original study were planning a pregnancy, not breastfeeding or using hormonal contraception, non-smokers, and they had no known pre-existing metabolic disorders (hypertension, diabetes, hyper- or hypothyroidism). After enrollment and consent, the preconception study visit included collection of maternal demographic data and completion of a 75 g oral glucose tolerance test to confirm absence of pre-existing diabetes mellitus.¹² For each visit, women presented after an 8–10 hour overnight fast. Study procedures relevant for the current analysis are described in detail.

Study procedures

Two weeks before their preconception visit, women met with a research nutritionist and were instructed to maintain a diet with macronutrient intake of 50% carbohydrate, 20% protein, and 30% fat. This counseling was reinforced as part of routine clinical care once a woman was pregnant, whether she remained normoglycemic or was diagnosed with gestational diabetes at time of routine third trimester screening.¹³ For a subset of women, diet and activity information was collected. Dietary intake was collected using a 24-hour recall food frequency questionnaire, reporting total kilocalories per day. Activity was measured using a leisure time activity questionnaire.¹⁴

Body composition was estimated using hydrodensitometry with correction for residual lung volume.¹⁵ Body fat percentage was calculated according to the equations of Keys and Brozek preconception¹⁶ and Catalano, et al.¹⁷ in late pregnancy adjusting for the changes in hydration constant in FFM in late pregnancy. Data are reported as total kilograms (kg), kg fat mass (FM), kg fat free mass (FFM), and percentage (%) body fat (kg FM/kg total body weight x 100). For this analysis, current World Health Organization definitions for body mass index (BMI, kg/m²) and Institute of Medicine Guidelines for gestational weight gain defined, respectively, BMI class (underweight, normal weight, overweight, obese)¹⁸ and gestational weight gain adherence (inadequate, adequate, excess).¹

Indirect calorimetry was performed after an 8–10 hour overnight fast with a ventilated hood system that was used for continuous collection and mixing of expired air as previously described.^{10, 11} Briefly, measurements of oxygen consumption and carbon dioxide production were collected over 45 minutes with the participant reclined, usually watching television. Standard gases were used before and after each procedure to calibrate oxygen (Applied Electrochemistry, Sunnyvale, CA; or Magnos 4G; Hartmann & Braun, Frankfurt, Germany) and infrared carbon dioxide (Applied Electrochemistry, Sunnyvale, CA, or Uras 3G, Hartmann & Braun, Frankfurt, Germany) analyzers. The coefficient of variation is 2–3% for indirect calorimetry measures. The total volume of expired air was corrected for standard temperature and pressure conditions. Data were collected every 10 seconds, averaged, and reported as a 5-minute average of total resting metabolic rate (kcal/min); data for this analysis were converted to and are reported as kcal/day.

Statistical analysis

We described the full cohort, reporting mean and standard deviation (SD) for continuous variables and proportions with total *n* (%) for categorical variables, and compared the percent change from preconception to late pregnancy using paired t-tests. We compared adherence to Institute of Medicine gestational weight gain guidelines for normal weight and overweight women; four underweight and four women who were obese were not included in categorical analyses by Institute of Medicine guidelines.

Resting energy expenditure (kcal/day) was reported at preconception, late pregnancy, and the change across those two time points. resting energy expenditure was also expressed per kilogram of fat free mass per day (kcal.kg FFM⁻¹.day⁻¹). Using Pearson's correlations, we measured whether each REE measure was associated with maternal change in fat mass (FM), FFM, or gestational weight gain; correlations are reported as *r*. Although data were primarily normally distributed, non-parametric analyses were also performed; results were consistent with reported parametric analyses. *P*<0.05 was considered significant for all analyses.

Results

Fifty-one women met inclusion criteria for this analysis. Mean age was 32 (4), 96% (49/51) were Caucasian, 80% (41/51) were parous, and 37% (19/51) were diagnosed with gestational diabetes during the third trimester. The cohort was largely normal weight (33/51, 65%) or overweight (10/51, 20%) with mean BMI 23.0 (4.7) kg/m². Weight and body

composition at preconception, late pregnancy (34.4 [1.0] weeks of pregnancy), and the percent change over time are shown in Table 2. FFM increased by 19 (6)%. FM increased but with wide variation, 30 (30)%. gestational weight gain was 12.8 (4.7) kg, and overweight, compared with normal weight, women were more likely to exceed the 2009 Institute of Medicine gestational weight gain guidelines (80% vs. 24%, $p=0.004$). Among 26 women for whom diet and activity data were available, caloric intake increased by ~5% from preconception to late pregnancy; leisure time activity score decreased almost 30%. Consideration of either measure as a potential covariate did not alter overall results.

On average, resting energy expenditure increased from 31.9 (2.6) to 34.1 (3.7) kcal.kg FFM⁻¹.day⁻¹, a change of 7 (11)%, $p=0.002$, and from 1428 (172) to 1820 (283) in kcal/day, a change of 27 (13)%, $p<0.001$. These changes in resting energy expenditure depicted in Figure 1A and 1B for individual women. Interestingly in Figure 1A, resting energy expenditure (kcal.kg FFM⁻¹.day⁻¹) actually decreased from preconception to late pregnancy in 25% (13/51) of women. Characteristics between women with a decreased, versus increased resting energy expenditure were similar. Specifically they were of similar age, equally likely diagnosed with gestational diabetes, and had similar preconception BMI. Body composition, diet, or leisure time activity, preconception, late pregnancy, and changes across pregnancy were also similar (data not shown). In Figure 1B, resting energy expenditure (kcal/day) increased across pregnancy for 98% of woman (50/51).

The association between preconception and late pregnancy measures of resting energy expenditure in kcal/day and resting energy expenditure in kcal.kg FFM⁻¹.day⁻¹, as well as the changes in body composition and total gestational weight gain are shown in Table 3. resting energy expenditure in kcal/day was positively associated with subsequent FFM both preconception ($r=0.37$, $p=0.008$) and late pregnancy ($r=0.51$, $p=0.001$). Only late pregnancy resting energy expenditure (kcal.kg FFM⁻¹.day⁻¹) was inversely associated with FM, or fat mass accrual across pregnancy ($r=-0.34$, $p=0.02$), as was gestational weight gain ($r=-0.29$, $p=0.04$). Diagnosis of gestational diabetes did not alter the magnitude or significance of these findings (data not shown).

Changes in resting energy expenditure in kcal/day over the course of gestation were positively correlated with FFM ($r=0.44$, $p=0.002$) but trended negatively with FM ($r=-0.27$, $p=0.06$), Figure 2. To illustrate the potential impact of these relationships on body composition changes (assumption being that nutritional intake and other components of physical activity were similar), consider two representative women with similar gestational weight gain. In Figure 2, participant A depicted by a vertical green line had a gestational weight gain of 14.0 kg. Participant B depicted by a vertical red line had a gestational weight gain of 13.7 kg. Participant A had a 749 kcal/day increase in resting energy expenditure through late pregnancy, with a corresponding gain of only 0.3 kg FM and 13.7 kg FFM; i.e. only 2% of her total gestational weight gain was FM accrual. In contrast, participant B with 50% less of an increase in resting energy expenditure (350 kcal/day) through late pregnancy, had a corresponding gain of 2.1 kg FM and 11.6 kg FFM; 15% of her gestational weight gain was FM accrual. Thus, because Participant B increased her resting energy expenditure by only half that of Participant A, despite similar total gestational weight gain, had a nearly 7-fold increase in FM accrual compared to Participant A.

Comment

Principal Findings

In a cohort of primarily normal and overweight women, resting energy expenditure increased significantly from preconception through late pregnancy, whether expressed as kcal/FFM/day, (7%) or kcal/day, (27%). It is important to estimate the change in resting energy expenditure both in terms of total energy expenditure (kcal/day) and adjusted for FFM. Because FFM represents metabolically active tissue (for example skeletal muscle) whereas fat mass is proportionately less metabolically active. Further, although the increase in FFM in pregnancy largely represents total body water, in pregnancy the increases in resting energy expenditure are related to both increases in FFM with or without adjustment for total body water.¹⁹ The 27 (13) % increase in kcal/day across pregnancy translates into a mean increase of almost 400 kcal/day with a standard deviation of almost 200 kcal/day, a clinically relevant variation. Most importantly, among these healthy women, a moderate increase in resting energy expenditure (kcal/day) had a greater impact on increased gestational weight gain, specifically FM but not FFM, compared with women who had substantially greater increases in resting energy expenditure (kcal/day). Further, our group has already demonstrated that, among overweight/obese women, excess gestational weight gain is comprised of primarily fat, and not fat free, mass.²⁰

Given the substantial proportion of total energy expenditure that is comprised of resting energy expenditure, approximately 60%, even small variations may have far-reaching implications for individual pregnant women. Our results confirm and extend the limited existing published data. The 27% increase in to a large extent (kcal/day) across pregnancy in our study is similar to the 25–30% increase in to a large extent (kcal/day) reported by others.^{21–24} Butte, et al,²² used a room calorimeter to measure total energy expenditure, including basal metabolic rate, whereas Kopp-Hoolihan, et. al.,²² in a sample of 10 women, and Lof, et. al.,²¹ in a sample of 23, mostly normal weight Swedish women, used an indirect calorimeter system similar to ours. Abeysekera, et. al²³ also measured to a large extent in a contemporary cohort of 26 mostly normal weight Swedish women. Although methodological and cohort differences exist among studies, each report an increased REE across pregnancy, consistent with our results.

Clinical Implications

The clinical implications of this study, in particular, show that resting energy expenditure is a significant variable related to changes in gestational weight gain and fat mass accrual. As discussed previously a common assumption, relating to gestational weight gain, is that increased energy intake and decreased physical activity explain excessive gestational weight gain. A recent meta-analysis of 18 studies, however, suggests there is very little increase in energy intake during pregnancy.²⁵ Other studies have shown a relatively consistent and predictable decrease in physical activity during pregnancy,^{26–28} thus also not likely explaining varied gestational weight gain or fat mass accrual. A recent publication, however, showed that an intensive physical activity intervention in a Chinese cohort, initiated prior to 20 weeks gestation, decreased the subsequent diagnosis of gestational diabetes. That study is not directly applicable to our cohort, and it is notable that the baseline prevalence of

gestational diabetes in that control group is much higher than expected in a U.S. cohort, close to 40%. Nonetheless, it suggests that altering physical activity early in gestation may still be of some benefit to perinatal outcomes.²⁹

Research Implications

Our data suggest an alternative physiologic variable associated with gestational weight gain and FM accrual. We report that the wide variation in individual to a large extent changes across pregnancy, whether defined as kcal/day or kcal/FFM, are associated with both increases and decreases in FM (10% of our cohort lost FM). Although preconception to a large extent was not associated with FM gains or losses during pregnancy, late pregnancy to a large extent was lower among women with greater FM accrual. Therefore, there is a metabolic alteration during pregnancy, which affects to a large extent. Although the underlying physiologic mechanisms for changes in REE are unknown, future research is needed to identify those metabolic alterations and establish if they are in any way modifiable during pregnancy. In the interim, estimating to a large extent in pregnancy maybe prove a useful adjunct to modifying nutritional intake.

Strength and Limitations

Strengths of this study include its prospective data collection and measures of to a large extent and body composition, and in a larger sample size than those reported previously. Indirect calorimetry is a reliable, reproducible estimate of to a large extent. Body composition estimates in late pregnancy use a pregnancy-specific hydration constant that accounts for physiologic changes in total body water content of lean tissue. Finally, preconception and late pregnancy measures describe a true longitudinal relationship.

The limitations of our study include the following. First, as ours is a cohort of primarily normal or overweight, Caucasian women. Our findings may not be generalizable to women who are underweight or obese, or those of other race/ethnicity. Second, although estimates of diet and physical activity did not appear to impact our findings, these data were available for only half the cohort and were based on questionnaire data that may over- or underestimate food intake and activity. Third, other important components of energy expenditure in pregnancy such as dietary-induced thermogenesis and measured physical activity, for example with an accelerometer, were not evaluated. Finally, a subset of our cohort was diagnosed with gestational diabetes by routine third trimester screening. Although inclusion or exclusion of women with gestational diabetes did not alter findings, this may not be the case with all gestational diabetes.

Conclusion

In summary, this analysis contributes to the limited contemporary publications measuring to a large extent and body composition in pregnancy. Our findings highlight the potential impact of changes in to a large extent relative to variations in gestational weight gain and FM. These data have implications for the long-term obesity related health and metabolism in women and their children. With the growing obesity crisis^{1, 30} and over half of women across BMI classes gaining excessive weight in pregnancy,^{31–33} research into factors

impacting to a large extent and diet and lifestyle intervention studies are of high research priority.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Preconception (Pre) to Late Pregnancy (Late) change in resting energy expenditure (REE).

A. REE, $\text{kcal} \cdot \text{kg FFM}^{-1} \cdot \text{d}^{-1}$, red lines with ● represent women with decreased REE across pregnancy, black lines with ▲ represent women with increased REE across pregnancy,

* $P=0.002$; B. REE, kcal/d , * $P<0.001$

Figure 2.

Change in resting energy expenditure (REE) in kcal/day is negatively associated with FM ($r=-0.27$, $p=0.06$) and positively associated with FFM ($r=0.44$, $p=0.002$); Data for cohort total $n=51$ were plotted; Representative data from two participants are highlighted; Participant A had a 14.0 kg gestational weight gain, 0.3 kg FM, 13.7 kg FFM, and 749 kcal/day REE increase, illustrated by vertical green line; Participant B had a 13.7 kg gestational weight gain, 2.1 kg FM, 11.6 kg FFM, and 350 kcal/day REE increase, illustrated by vertical red line

Table 1

2009 Institute of Medicine Guidelines for Weight Gain in Pregnancy

Prepregnancy body mass index	Body mass index (kg/m ²)	Total weight gain (lbs)	Rates of Weight Gain 2 nd and 3 rd trimesters (mean range, lbs/week)
Underweight	< 18.5	28 – 40	1 (1 – 1.3)
Normal weight	18.5 – 24.9	25 – 35	1 (0.8 – 1)
Overweight	25.0 – 29.9	15 – 25	0.6 (0.5 – 0.7)
Obese (all classes)	> 30.0	11 – 20	0.5 (0.4 – 0.6)

Table 2

Maternal body composition preconception, late pregnancy, and percent change over time

	Preconception	Late pregnancy	
	Mean (SD)		Percent change over time ^a
Weight, kg	63.9 (13.6)	76.8 (14.5)	21 (8)
Body mass index, kg/m ²	23.0 (4.7)	27.6 (4.8)	21 (8)
Fat free mass, kg	44.8 (4.8)	53.4 (6.4)	19 (6)
Fat mass, kg	19.1 (10.3)	23.4 (9.8)	30 (30)
Percent fat mass, %	28.4 (8.3)	29.5 (6.6)	7 (20)

^aPercent change over time = (late pregnancy-preconception)/preconception; $P < 0.001$ for all

Table 3

Correlations between preconception and late pregnancy energy expenditure and maternal body composition changes

	Preconception		Late Pregnancy	
	r	P=	r	P=
Correlation between kcal/day and,				
FM	-0.05	0.72	-0.21	0.14
FFM	0.37	0.008	0.51	0.001
GWG, kg	0.19	0.17	0.16	0.27
Correlation between kcal.kg FFM ⁻¹ .day ⁻¹ and,				
FM	-0.19	0.2	-0.34	0.02
FFM	0.17	0.2	-0.04	0.8
GWG, kg	-0.04	0.8	-0.29	0.04

change; FM, fat mass; FFM, fat free mass; GWG, gestational weight gain