Published in final edited form as:

Obstet Gynecol. 2016 May ; 127(5): 884–892. doi:10.1097/AOG.0000000000001372.

Energy Intake and Energy Expenditure for Determining Excess Weight Gain in Pregnant Women

L. Anne Gilmore, Ph.D.¹, Nancy F. Butte, Ph.D.², Eric Ravussin, Ph.D.¹, Hongmei Han, M.S.¹, Jeffrey H. Burton, Ph.D.¹, and Leanne M. Redman, Ph.D.¹

¹Pennington Biomedical Research Center

²Baylor College of Medicine

Abstract

Objective—To conduct a secondary analysis designed to test whether gestational weight gain is due to increased energy intake or adaptive changes in energy expenditures.

Methods—In this secondary analysis, energy intake and energy expenditure of 45 pregnant women (BMI 18.5–24.9 kg/m², n=33 and BMI ≥ 25, n=12) were measured preconceptionally 22, and 36 weeks of gestation. Energy intake was calculated as the sum of total energy expenditure measured by doubly labeled water and energy deposition determined by the 4-compartment body composition model. Weight, body composition, and metabolic chamber measurement were completed preconceptionally, 9, 22, and 36 weeks of gestation. Basal metabolic rate was measured by indirect calorimetry in a room calorimeter and activity energy expenditure by doubly labeled water.

Results—Energy intake from 22 to 36 weeks of gestation was significantly higher in high gainers (n=19) (3437 ± 99 kcal/d) versus low + ideal gainers (n=26) (2687 ± 110 p< .001) within both BMI categories. Basal metabolic rate increased in proportion to gestational weight gain; however, basal metabolic rate adjusted for body composition changes with gestational weight gain was not significantly different between high gainers and low + ideal gainers (151 ± 33 vs. 129 ± 36 kcal/d; p=.66). Activity energy expenditure decreased throughout pregnancy in both groups (low + ideal gainers: –150 ± 70 kcal/d; p=.04 and high gainers: –230 ± 92 kcal/day; p=.01), but there was no difference between high gainers and low + ideal gainers (p=.49).

Conclusion—Interventions designed to increase adherence to the IOM guidelines for weight gain in pregnancy may have increased efficacy if focused on limiting energy intake while increasing nutrient density and maintaining levels of physical activity.

Address for correspondence: Leanne M. Redman, PhD, Pennington Biomedical Research Center, 6400 Perkins Rd, Baton Rouge, LA 70808, leanne.redman@pbrc.edu.

Financial Disclosure

The authors did not report any potential conflicts of interest.

Presented at Obesity Week November 11–16, 2013 in Atlanta, GA (T-79-OR).

Introduction

Energy intake and energy expenditure are considered to be the two primary determinants of weight gain in humans. However, little is known regarding changes in energy intake and energy expenditure during pregnancy and the effect on gestational weight gain (GWG). Given that 48% percent of all pregnant women exceed the 2009 Institute of Medicine (IOM) recommendations for GWG (1), understanding the roles of energy intake and energy expenditure during pregnancy in relation to GWG is important for the development of successful weight management programs for this population.

Self-reported food intake is not different for women who achieved the recommended weight gain and those who had excessive weight gain (2). However, most individuals significantly under-report energy intake (3, 4) even during pregnancy (5). Objective assessments of energy intake are thereby critically important to enhance the fundamental understanding of how changes in energy intake contribute to weight gain in pregnant women.

Many investigators believe compensatory changes in energy metabolism in response to increased food intake, contribute to the variability in weight gain (6–9). Furthermore, a low resting metabolic rate has been demonstrated to be a determinant of weight gain in non-pregnant adults (10). Quantifying the changes in energy metabolism during pregnancy in relation to GWG is needed to direct intervention strategies.

Using a unique dataset that includes prospective objective and highly reliable measures of energy intake and expenditure throughout pregnancy (11), we tested the hypothesis that when compared to those women who gain weight below or in accordance with the 2009 IOM guidelines for GWG, women will exceed the guidelines through the following mechanisms: 1) increased energy intake, 2) increased energy expenditure but less than expected for the changes in body composition, and 3) decreased physical activity.

Materials and Methods

The parent study was approved by Institutional Review Board for Human Subject Research for Baylor College of Medicine and Affiliated Hospitals, funded by the United States Department of Agriculture and Department of the Army, and completed prior to 2007, and thus was not required to register with ClinicalTrials.gov. Individuals were recruited through local newspapers and community fliers. Informed written consent was obtained from each woman. LAG, LMR, ER, HH, JB received a dataset containing individual, de-identified data from NFB. The statistical analysis plan for this work was reviewed by the Institutional Review Board at Pennington Biomedical Research Center, but was exempt from approval.

This secondary analysis included 45 women with a body mass index of 18.5 – 35.4 kg/m² who participated in a comprehensive study of changes in body composition and energy expenditure throughout pregnancy (11). The initial study included 63 women who were nonsmokers, nonanemic, normotensive, normoglycemic, and euthyroidic both at enrollment and throughout pregnancy. For this analysis, a priori criteria for exclusion included women with a BMI <18.5 kg/m² (n=3) or individuals with incomplete data during either the second or third trimester (n=15). The remaining patients (n=45) were categorized on the basis of

prepregnancy BMI defined as normal weight (BMI 18.5 – 24.9 kg/m²) and overweight and obese (BMI ≥ 25 kg/m²) obtained from actual measurements of weight and height prior to the index pregnancy.

The primary objective of the parent study was to estimate the energy requirements of pregnant women and to explore energetic adaptations that occur during pregnancy. Clinical assessments weight, body composition, and metabolic chamber measurement were completed prior to estimated date of conception (179±184 days), and at 9, 22, and 36 weeks of gestation. Fourteen day doubly labeled water studies were completed at week 0, 22, and 36 weeks of gestation (Table 1). The application and adaption of these measures to address the primary aim of this secondary analysis are described below.

Fat mass (kg) and fat-free mass (kg) were calculated from a four-component model incorporating body weight (kg), body density measured by hydrostatic (underwater) weighing, total body water (L) from ²H dilution, body volume (L), and bone mineral content obtained prepregnancy using DXA (Table 2) (12).

Total weight gain for each individual was compared to the appropriate prepregnancy body mass index (BMI) classification specific IOM recommendations. As there were few women (n=3) with a prepregnancy BMI ≥30, these women were combined with the overweight women (BMI ≥25); however, the respective BMI specific IOM recommendations were used to determine adherence. Those individuals who exceeded the IOM guidelines (n=19) were classified as “high gainers”. No women with a BMI ≥ 25 kg/m² gained below the IOM recommendations, so individuals who gained below (n=12) or within (n=14) the IOM guidelines were combined into one group collectively classified as “low + ideal gainers”. Total GWG was calculated as weight gain between preconception and last measured study weight during pregnancy (36 weeks of gestation; Table 2).

The energy balance method provides a reliable estimation of energy intake during a period of weight change through the use of doubly labeled water to estimate total energy expenditure and quantification of the changes in body energy stores (i.e. fat mass and fat free mass). The energy balance theory relies on the assumption of linear weight gain, as does the IOM GWG recommendations in the second and third trimesters. Therefore, we used body composition changes between the second (week 22) and third trimester (week 36) to estimate energy intake during that period. Changes in fat mass and fat-free mass between the second and third trimester were converted to energy (kcal/d) using previously published energy coefficients for protein and fat deposition in pregnant women; 0.771 and 9.5 kcal/g, respectively (13). Total energy intake was the sum of total energy expenditure measured by doubly labeled water and the energy deposited as fat or fat free mass during that period (Table 2).

Basal metabolic rate was measured in a metabolic chamber (14) preconception, and at 9, 22 and 36 weeks of gestation. In brief, participants consumed meals at 0830, 1200, and 1730 with a snack at 1830. No food was allowed after 1900. Bedtime was at 2200. Participants were awakened at 0645, were asked to void, and returned to sleep. The participant was again awakened about 30 min later and basal metabolic rate was measured for 40 min while the

participant remained motionless in bed. Basal metabolic rate was calculated by the Weir equation (15). Obligatory changes in basal metabolic rate were computed from the unadjusted data (absolute kcal/d). Adaptive changes in basal metabolic rate at the third trimester time point were determined as the difference between the measured basal metabolic rate and the basal metabolic rate predicted from a linear regression model for basal metabolic rate using fat mass and fat-free mass during the second trimester and maternal age at gestation as predictors (Table 2).

Details regarding the doubly labeled water method to determine total energy expenditure can be found in the parent study publication (11). In brief, after a baseline saliva sample was collected, the women received an oral dose of 100 ml of $^2\text{H}_2\text{O}$ and 125 mg H_2^{18}O (Cambridge Isotope Laboratories) per kg body weight. A daily saliva sample was then taken for 13 days. Saliva samples were analyzed for hydrogen and oxygen isotope ratio measurements by gas-isotope-ratio mass spectrometry (16). Turnover rates of ^2H and ^{18}O were converted to total energy expenditure using the Weir equation (15) and a food quotient of 0.86, the value traditionally used based on the standard American diet (23). Adaptive changes in total energy expenditure at the third trimester were determined as the difference between the measured total energy expenditure and the predicted total energy expenditure. Predicted total energy expenditure was calculated from a linear regression model for total energy expenditure using fat mass and fat-free mass during the second trimester and maternal age at gestation as predictors (Table 2).

The energy expenditure of activity was estimated from non-basal energy expenditure where the thermic effect of food was assumed to be 10% of total energy expenditure for all individuals. The physical activity level was estimated as the ratio between total energy expenditure and basal metabolic rate.

Data in the text and tables are provided as mean $\pm$ SE. All calculations and data analyses were performed using SAS Version 9.4 (SAS Institute, Cary, NC). The changes in variables across pregnancy were analyzed by fitting linear models for repeated measures with adherence to the 2009 GWG Guidelines (low + ideal vs. high gainers) and BMI classification as covariates. Differences in these changes between groups were investigated by comparing least squares means via two-sample t-tests. Multiple linear regression models were used to generate equations for predicting Total energy expenditure and basal metabolic rate by utilizing data observed during the second trimester ($n=45$). Third trimester total energy expenditure and basal metabolic rate were predicted by plugging observed third trimester fat-free mass and fat mass values into the predictive equations. The differences between measured and predicted total energy expenditure and basal metabolic rate values were calculated and analyzed using linear models. Fisher's exact test was used to assess relation of preconception BMI class and adherence to the IOM GWG Guidelines. $P<0.05$ was considered statistically significant. The minimum detectable effect size for the primary outcome, energy intake, is 365 kcal/d with $n = 45$, $\sigma = 864$ kcal/d, $\alpha = 0.05$, and power of 0.8.

Results

Baseline characteristics are summarized in Table 3. There were no significant differences between ideal+low and high gainers for age at conception, menarche age, maternal education, self-identified race, gravidity, and parity. One patient in the low+ideal gainer group received ovulation stimulation therapy prior to conception. As described in more detail below, preconception BMI was higher in the high gainers than the low+ideal gainers.

Thirty-three women were normal weight ($18.5\text{--}24.9\text{ kg/m}^2$) at conception of whom 9 gained above the IOM Guidelines and 24 who gained below or within the IOM guidelines. Twelve women were overweight or obese ($\geq 25\text{ kg/m}^2$) at conception, ten of whom gained above the IOM guidelines and two who gained within the guidelines. No women with a preconception BMI $\geq 25\text{ kg/m}^2$ gained below the IOM guidelines. Weight gain was significantly higher in the women who had a preconception BMI $\geq 25\text{ kg/m}^2$ than the women of normal weight prior to conception (17 ± 1.5 vs. 13.5 ± 0.8 kg; $p=.03$).

Of the low + ideal group ($n=26$), 12 women gained below the IOM guidelines and 14 gained within. Those who gained below the IOM guidelines gained 8.9 ± 1.9 kg (range: $3.7\text{--}10.9$ kg) which is 2.6 kg less than what is recommended by the IOM. Weight gain in the low + ideal gainers was 10.9 ± 0.8 with 2.2 ± 1.6 kg as FM (20%) and 7.8 ± 1.5 kg as FFM (Table 4). The high gainers ($n=19$) gained a total of 18.7 ± 0.7 kg with 9.1 ± 0.8 kg gained as FM (49%) and 9.2 ± 0.7 kg gained as FFM. Fisher's exact test showed a significant association between BMI classification and whether IOM guidelines for GWG were exceeded, with women who were overweight or obese before pregnancy having a higher percentage exceeding the guidelines than women with normal BMI before pregnancy (83% vs 27%, $p=.0019$).

By nature of study design, high gainers gained more weight throughout the entire pregnancy than low + ideal gainers (18.7 ± 0.7 vs. 10.9 ± 0.8 kg; $p<.001$). Further, high gainers gained more weight in the first 9 weeks than low + ideal gainers ($p=.008$). High gainers gained an average of 3.2 ± 0.7 kg for the first 9 weeks while low + ideal gainers maintained their preconception weight (0.09 ± 0.8 kg). From week 9 to week 22, high gainers gained 6.6 ± 0.4 kg in comparison to 4.7 ± 0.5 kg gained by low + ideal gainers ($p<.05$). In the final observation period from week 23 to week 36, high gainers added another 8.9 ± 0.6 kg by week 36 while low gainers added 5.8 ± 0.7 kg ($p=.0015$; Figure 1).

On the basis of the intake-balance method, energy intake of the high gainers was estimated as 3437 ± 99 kcal/day on average from 22 to 36 weeks of gestation while the energy intake of the low + ideal gainers was 2687 ± 110 kcal/day (Table 4). High gainers thereby consumed 750 ± 150 kcal/d more than the low + ideal gainers, which was significant ($p<.001$). The observed difference in energy intake between high and low + ideal gainers was evident within each BMI category; however, energy intake was not different across the two BMI groups (Figure 2).

Basal metabolic rate increased in proportion to weight gain throughout pregnancy for both low + ideal gainers and high gainers. Therefore, as expected, this obligatory increase in metabolic rate led to significantly higher basal metabolic rate for high gainers in comparison

to the low + ideal gainers in the third trimester (1913 ± 43 vs. 1681 ± 47 kcal/d; $p=.0011$). Similarly, when predicting the third trimester basal metabolic rate on the basis of changes in maternal fat free mass, fat mass and maternal age, predicted basal metabolic rate was higher in high gainers than in low + ideal gainers (1762 ± 21 vs. 1547 ± 23 vs. kcal/d; $p<.001$; Table 4). The adaptive changes in basal metabolic rate, computed as the measured basal metabolic rate minus the basal metabolic rate predicted for maternal characteristics (basal metabolic rate residuals), was significantly different from zero in both high gainers ($p<.001$) and low + ideal gainers ($p=.001$), which suggests an adaptive response in energy expenditure throughout pregnancy. Adaptive basal metabolic rate was not significantly different however between low + ideal gainers and high gainers (129 ± 36 vs. 151 ± 33 kcal/d; $p=.66$; Figure 3).

Similarly, assessment of whole-body energy expenditure by doubly labeled water over 14 days, showed that total energy expenditure in the third trimester was significantly higher in high gainers compared to low + ideal gainers (3028 ± 88 vs. 2656 ± 98 vs. kcal/d; $p=.0078$), but did not differ between BMI groups. Interestingly, the measured total energy expenditure did not differ from the predicted total energy expenditure (2646 ± 36 vs. 2976 ± 32 kcal/d) between high gainers and low + ideal gainers ($p=.73$) or between BMI groups ($p=.91$; Table 4).

Activity energy expenditure decreased throughout pregnancy in both low + ideal (-150 ± 70 kcal/d; $p=.04$) and high gainers (-230 ± 92 kcal/d; $p=.01$), but no differences were seen between high gainers and low + ideal gainers ($p=.49$; Table 4).

Similar to activity energy expenditure, physical activity level decreased throughout pregnancy for both the low + ideal (-0.26 ± 0.06 ; $p<.001$) and high gainers (-0.31 ± 0.07 ; $p<.001$), but no differences were observed between the two groups ($p=.61$; Table 4).

Discussion

Pregnancy is an expected time for positive energy balance and weight gain. The estimated energy intake in both gainer groups derived from these objective methods may be thought to be substantially higher than needed to support gestational weight gain, however these results are consistent with other objective methods of estimation including indirect calorimetry (17–19). Furthermore, using a gestational weight gain and energy intake calculator (13) validated by doubly labeled water studies in pregnant women, the energy requirement to maintain weight in this study cohort is 2368 kcal/d computed from the average preconception weight, height, and age of the patients. To gain within the IOM guidelines the calculator recommends a 129 kcal/d increase in calories during trimester 1, an additional 249 kcal/d increase in trimester 2, and an additional 108 kcal/d increase in trimester 3. These trimester specific increases are consistent to those recommended in textbooks and the scientific literature (e.g. minimal increase in kcals in the first trimester and 300–500 kcal/d during the 2nd and 3rd trimester depending on the individual) (11, 20). The perceived high energy intakes then would be due to inaccurate assumptions of the energy requirement. The equations commonly used in clinical practice (i.e. Mifflin St. Jeor, Harris-Benedict) estimate resting metabolic rate or basal metabolic rate for the population in general and then a trained

individual selects activity and illness factors to determine daily energy requirements (21, 22). Luckily in this study, we were able to estimate energy requirement in trimester 2 using doubly labeled water which is the most accurate way to estimate total energy expenditure in free living individuals (23, 24). Estimated energy intake in trimester 3 is the doubly labeled water total energy expenditure measured in trimester 2 plus the energy stored as fat and muscle mass specific to each patients weight gain. These results are objective, individualized, and free from human bias and reflect the true energy intake needed to support the gestational weight gain we observed. The truth is that under-reporting intake is highly prevalent, even with new smartphone applications and many individuals fail to comprehend the energy density of food being consumed (3–5).

With objective measures we observed that weight gain in excess of the 2009 IOM GWG guidelines occurred as a result of increased energy intake, not a reduction or a conservation of energy being expended. Women who exceeded the 2009 Guidelines consumed approximately 800 kcal/d more than those who gained weight below or within the guidelines. At first glance, a contributing factor to explain the increased energy intake within the high gainers would be that excess GWG was more prevalent in women with a BMI ≥ 25 kg/m². One would assume that these women would have a higher energy intake to support their increased metabolic size. However, our data does not support this. Interestingly, we observed that the difference in energy intake between high gainers and low + ideal gainers was evident in both BMI categories and the average energy intake for both BMI categories was not significantly different. Arguably, the largest discrepancy in energy intake between low + ideal gainers and high gainers likely originated in the first trimester when the high gainers gained 3.2 kg whereas women defined as low + ideal gainers maintained weight during this same period of time. High gainers continued on this excessive weight gain trajectory and thereby gained significantly more weight throughout the entire pregnancy than low + ideal gainers. This observation is consistent with Knabl et al. (25) observations that total GWG and adherence to the IOM GWG guidelines are predicted by weight gain in the first trimester.

Previous research agrees that energy expenditure, that is basal metabolic rate or total daily energy expenditure, increases as pregnancy progresses and as the metabolic size of the individual increases (5, 26–28). However, in some individuals an additional increase in energy expenditure that exceeds the expected increase for the change in metabolic mass is observed which is believed to allow the body to ‘waste’ excess calories being consumed in an attempt to maintain body weight or return the body weight to habitual levels (8). While the evidence for metabolic adaptation during weight loss is strong (8), the evidence supporting adaptations with weight gain is less clear (7–9, 29, 30). Leibel et al. (31) observed significant increases in TEE, non-resting energy expenditure, and the thermic effect of food after a 10% weight gain in non-pregnant adult. As a result of 20% weight gain in the present study, we observed an increased basal metabolic rate over what we would predict for the increase in maternal metabolic size lending to the observation of metabolic adaptation in pregnancy, but this occurred in both high and low gainers. However, there was no difference between measured total energy expenditure and predicted total energy expenditure which is likely due to a decrease in the energy cost of activity in both groups.

From a physiological perspective, the unnecessary wasting of energy during pregnancy is unlikely because the mother would presumably be striving to maximize metabolic efficiency to ensure all excess energy consumed is partitioned for maternal energy stores in order to promote survival and growth of the infant during pregnancy and preparation for lactation that follows. More probable than adaptive thermogenesis is an underestimation of predicted basal metabolic rate in pregnant women due to failure to account completely for fetal mass, which is greatest within the third trimester (32), in the prediction equations. A follow up study, MomEE (NCT01954342), is currently underway in our laboratory which will use MRI coupled with fetal ultrasound in an attempt to more accurately account for changes in maternal and fetal energy stores to allow for more thorough estimates of maternal energy intake and energy expenditure in obese pregnant women.

Our results suggest weight management interventions in pregnancy should be focused on controlling energy intake and maintaining physical activity. Indeed, in pregnant women with an overweight or obese preconception BMI, success in adherence to the IOM GWG recommendations has been seen with caloric restriction with weight maintenance recommendations, (33) and the use of partial meal replacements may be a practical tool to achieve the needed dietary control (34). To manage GWG in obese pregnant women, Vesco et al. (35) recently recommended a 30% caloric reduction to maintain weight ($\pm 3\%$) during obese pregnancy. Though weight maintenance during pregnancy goes against traditional recommendations, it was met with success in their trial with more women adhering to the 2009 IOM GWG guidelines and a significantly lower prevalence of large for gestational age infants born from the obese cohort.

Although the parent study is a landmark study with one of the largest samples in which energy intake and expenditure were objectively assessed longitudinally throughout pregnancy, this secondary analysis suffers from limited numbers with each BMI and IOM adherence category. Further research is needed, especially in women with a preconception BMI $\geq 25 \text{ kg/m}^2$ to better assess differences within BMI and IOM adherence categories. Researchers and clinicians should be encouraged to conduct medically managed interventions focusing on appropriate levels of energy intake to help women successfully adhere to the IOM GWG guidelines and achieve positive pregnancy outcomes.

Acknowledgments

Supported by NIDDK nutrition obesity research center funding (NIH-2P30DK072476), and grants to Leanne M. Redman (R00HD060762, U01DK094418, R01DK099175), Eric Ravussin (R01DK060412), and in support of L. Anne Gilmore by T32DK064584. This work was supported in part (Hongmei Han and Jeffrey H. Burton) by 1 U54 GM104940 from the National Institute of General Medical Sciences of the National Institutes of Health, which funds the Louisiana Clinical and Translational Science Center.

References

1. Dalenius, K.; Borland, E.; Smith, B.; Polhamus, B.; Grummer-Strawn, L. Pregnancy Nutrition Surveillance 2010 Report. Atlanta: U.S. Department of Health and Human Services Centers for Disease Control and Prevention; 2012.
2. Shin D, Bianchi L, Chung H, Weatherspoon L, Song WO. Is Gestational Weight Gain Associated with Diet Quality During Pregnancy? Maternal and child health journal. 2013 Oct 27.

3. Hill RJ, Davies PS. The validity of self-reported energy intake as determined using the doubly labelled water technique. *The British journal of nutrition*. 2001 Apr; 85(4):415–30. [PubMed: 11348556]
4. Trabulsi J, Schoeller DA. Evaluation of dietary assessment instruments against doubly labeled water, a biomarker of habitual energy intake. *American journal of physiology Endocrinology and metabolism*. 2001 Nov; 281(5):E891–9. [PubMed: 11595643]
5. Goldberg GR, Prentice AM, Coward WA, Davies HL, Murgatroyd PR, Wensing C, et al. Longitudinal assessment of energy expenditure in pregnancy by the doubly labeled water method. *Am J Clin Nutr*. 1993 Apr; 57(4):494–505. [PubMed: 8460604]
6. Hall KD. Predicting metabolic adaptation, body weight change, and energy intake in humans. *American journal of physiology Endocrinology and metabolism*. 2010 Mar; 298(3):E449–66. [PubMed: 19934407]
7. Diaz EO, Prentice AM, Goldberg GR, Murgatroyd PR, Coward WA. Metabolic response to experimental overfeeding in lean and overweight healthy volunteers. *Am J Clin Nutr*. 1992 Oct; 56(4):641–55. [PubMed: 1414963]
8. Dulloo AG, Jacquet J, Montani JP, Schutz Y. Adaptive thermogenesis in human body weight regulation: more of a concept than a measurable entity? *Obesity reviews : an official journal of the International Association for the Study of Obesity*. 2012 Dec; 13(Suppl 2):105–21. [PubMed: 23107264]
9. Joosen AM, Westerterp KR. Energy expenditure during overfeeding. *Nutrition & metabolism*. 2006; 3:25. [PubMed: 16836744]
10. Ravussin E, Swinburn BA. Metabolic predictors of obesity: cross-sectional versus longitudinal data. *International journal of obesity and related metabolic disorders : journal of the International Association for the Study of Obesity*. 1993 Dec; 17(Suppl 3):S28–31. discussion S41–2.
11. Butte NF, Wong WW, Treuth MS, Ellis KJ, Smith EOB. Energy requirements during pregnancy based on total energy expenditure and energy deposition. *The American Journal of Clinical Nutrition*. 2004; 79:1078–87. [PubMed: 15159239]
12. Fuller NJ, Jebb SA, Laskey MA, Coward WA, Elia M. Four-component model for the assessment of body composition in humans: comparison with alternative methods, and evaluation of the density and hydration of fat-free mass. *Clinical science*. 1992 Jun; 82(6):687–93. [PubMed: 1320550]
13. Thomas DM, Navarro-Barrientos JE, Rivera DE, Heymsfield SB, Bredlau C, Redman LM, et al. Dynamic energy-balance model predicting gestational weight gain. *Am J Clin Nutr*. 2012 Jan; 95(1):115–22. [PubMed: 22170365]
14. Moon JK, Vohra FA, Valerio Jimenez OS, Puyau MR, Butte NF. Closed-loop control of carbon dioxide concentration and pressure improves response of room respiration calorimeters. *The Journal of nutrition*. 1995 Feb; 125(2):220–8. [PubMed: 7861249]
15. Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. *The Journal of physiology*. 1949 Aug; 109(1–2):1–9. [PubMed: 15394301]
16. Wong WW, Lee LS, Klein PD. Deuterium and oxygen-18 measurements on microliter samples of urine, plasma, saliva, and human milk. *Am J Clin Nutr*. 1987 May; 45(5):905–13. [PubMed: 3578092]
17. Redman LM, Kraus WE, Bhapkar M, Das SK, Racette SB, Martin CK, et al. Energy requirements in nonobese men and women: results from CALERIE. *Am J Clin Nutr*. 2014 Jan; 99(1):71–8. [PubMed: 24257721]
18. Melzer K, Schutz Y, Boulvain M, Kayser B. Pregnancy-related changes in activity energy expenditure and resting metabolic rate in Switzerland. *European journal of clinical nutrition*. 2009 Oct; 63(10):1185–91. [PubMed: 19550432]
19. Prentice AM, Spaaij CJ, Goldberg GR, Poppitt SD, van Raaij JM, Totton M, et al. Energy requirements of pregnant and lactating women. *European journal of clinical nutrition*. 1996 Feb; 50(Suppl 1):S82–110. discussion S10–1. [PubMed: 8641268]
20. Trumbo P, Schlicker S, Yates AA, Poos M. Food, Nutrition Board of the Institute of Medicine TNA. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein

and amino acids. *Journal of the American Dietetic Association*. 2002 Nov; 102(11):1621–30. [PubMed: 12449285]

21. Frankenfield D, Roth-Yousey L, Compher C. Comparison of predictive equations for resting metabolic rate in healthy nonobese and obese adults: a systematic review. *Journal of the American Dietetic Association*. 2005 May; 105(5):775–89. [PubMed: 15883556]
22. Mifflin MD, St Jeor ST, Hill LA, Scott BJ, Daugherty SA, Koh YO. A new predictive equation for resting energy expenditure in healthy individuals. *Am J Clin Nutr*. 1990 Feb; 51(2):241–7. [PubMed: 2305711]
23. Wong WW, Roberts SB, Racette SB, Das SK, Redman LM, Rochon J, et al. The doubly labeled water method produces highly reproducible longitudinal results in nutrition studies. *The Journal of nutrition*. 2014 May; 144(5):777–83. [PubMed: 24523488]
24. Schoeller DA, van Santen E. Measurement of energy expenditure in humans by doubly labeled water method. *Journal of applied physiology: respiratory, environmental and exercise physiology*. 1982 Oct; 53(4):955–9.
25. Knabl J, Riedel C, Gmach J, Ensenauer R, Brandhuber L, Rasmussen KM, et al. Prediction of excessive gestational weight gain from week-specific cutoff values: a cohort study. *Journal of perinatology : official journal of the California Perinatal Association*. 2014 May; 34(5):351–6. [PubMed: 24577434]
26. Kopp-Hoolihan LE, van Loan MD, Wong WW, King JC. Longitudinal assessment of energy balance in well-nourished, pregnant women. *Am J Clin Nutr*. 1999 Apr; 69(4):697–704. [PubMed: 10197571]
27. de Groot LC, Boekholt HA, Spaaij CK, van Raaij JM, Drijvers JJ, van der Heijden LJ, et al. Energy balances of healthy Dutch women before and during pregnancy: limited scope for metabolic adaptations in pregnancy. *Am J Clin Nutr*. 1994 Apr; 59(4):827–32. [PubMed: 8147326]
28. White CR, Seymour RS. Mammalian basal metabolic rate is proportional to body mass^{2/3}. *Proceedings of the National Academy of Sciences of the United States of America*. 2003 Apr 1; 100(7):4046–9. [PubMed: 12637681]
29. Dulloo AG. Regulation of body composition during weight recovery: integrating the control of energy partitioning and thermogenesis. *Clinical nutrition*. 1997 Mar; 16(Suppl 1):25–35. [PubMed: 16844618]
30. Prentice AM, Goldberg GR, Davies HL, Murgatroyd PR, Scott W. Energy-sparing adaptations in human pregnancy assessed by whole-body calorimetry. *The British journal of nutrition*. 1989 Jul; 62(1):5–22. [PubMed: 2789988]
31. Leibel RL, Rosenbaum M, Hirsch J. Changes in energy expenditure resulting from altered body weight. *The New England journal of medicine*. 1995 Mar 9; 332(10):621–8. [PubMed: 7632212]
32. Fenton TR. A new growth chart for preterm babies: Babson and Benda's chart updated with recent data and a new format. *BMC pediatrics*. 2003 Dec 16; 3:13. [PubMed: 14678563]
33. Vesco KK, Karanja N, King JC, Gillman MW, Leo MC, Perrin N, et al. Efficacy of a group-based dietary intervention for limiting gestational weight gain among obese women: A randomized trial. *Obesity*. 2014 Sep; 22(9):1989–96. [PubMed: 25164259]
34. Phelan S, Phipps MG, Abrams B, Darroch F, Schaffner A, Wing RR. Randomized trial of a behavioral intervention to prevent excessive gestational weight gain: the Fit for Delivery Study. *Am J Clin Nutr*. 2011 Apr; 93(4):772–9. [PubMed: 21310836]
35. Vesco KK, Karanja N, King JC, Gillman MW, Perrin N, McEvoy C, et al. Healthy Moms, a randomized trial to promote and evaluate weight maintenance among obese pregnant women: study design and rationale. *Contemporary clinical trials*. 2012 Jul; 33(4):777–85. [PubMed: 22465256]

Figure 1. Comparison of trimester-specific weight gain between high gainers and low and ideal gainers. * $P < .05$ for between group differences.

Figure 2. Maternal energy intake determined from doubly labeled water and changes in maternal energy stores for high and low and ideal gainers (A) and body mass index class differences (B). * $P < .05$ for between group differences.

Figure 3.

Maternal energy expenditure (measured compared with predicted) for basal metabolic rate (A) and total energy expenditure (B) for high and low and ideal gainers. Basal metabolic rate was measured by indirect room calorimetry. Total energy expenditure was measured via doubly labeled water. Predicted basal metabolic rate and predicted total energy expenditure was calculated using a linear regression model for basal metabolic rate and total energy expenditure, respectively, using fat mass and fat-free mass during the second trimester and maternal age as predictors. See Table 2 for equations. * $P < .05$; † $P = .05$.

Table 1

Assessment Schedule

Assessment	Preconception [*]	First Trimester [†]	Second Trimester [‡]	Third Trimester [§]
Height	X			
Weight	X	X	X	X
Hydrostatic Weighing ^{//}		X	X	X
DXA [¶]	X			
DLW [#]	X		X	X
Metabolic Chamber Stay ^{**}		X	X	X

^{*} Assessments prepregnancy were completed at 179±184 days prior to estimated conception date

[†] Assessments during the first trimester were completed at week 9 of gestation

[‡] Assessments during the second trimester were completed at week 22 of gestation

[§] Assessments during the third trimester were completed at week 36 of gestation

^{//} Hydrostatic weighing was used to calculate body volume which was used in the four compartment model for fat mass and then fat free mass

[¶] DXA: Dual-energy x-ray absorptiometry; used to measure bone mineral content used in four compartment model for body composition

[#] DLW: Doubly labeled water; used to measure energy expenditure (total energy expenditure, physical activity level, and activity energy expenditure), energy intake, total body water

^{**} Metabolic chamber stay used to measure basal metabolic rate (BMR). BMR was used to calculate physical activity level and activity energy expenditure

Table 2

Equations for variable calculations *

Variable	Equation
Fat Mass (kg)	$FM = 2.747 \text{ body volume (L)} - 0.71 \text{ TBW (L)} + 1.46 \text{ BMC (g/cm)} - 2.05 \text{ weight (kg)}$
Fat Free Mass (kg)	$FFM = \text{weight (kg)} - FM \text{ (kg)}$
Total Gestational Weight Gain (kg)	$\text{Total GWG} = \text{Weight measured in trimester 3 (kg)} - \text{Prepregnancy weight (kg)}$
Energy Intake (kcal/d)	$\text{Week 36 Energy Intake} = \text{Week 22 TEE (kcal/d)} + 9.5 \text{ (kcal/g)} \times FM \text{ (week 22 to week 36; g)} + 0.771 \text{ (kcal/g)} \times FFM \text{ (week 22 to week 36; g)}$
Predicted Basal Metabolic Rate (kcal/d)	$BMR_p = 518.9 + 12.0 \times FM \text{ (kg)} + 18.1 \times FFM \text{ (kg)} - 5.1 \times \text{Age (y)}$
Predicted Total Energy Intake (kcal/d)	$TEE_p = 1528 + 13.6 \times FM \text{ (kg)} + 29.4 \times FFM \text{ (kg)} - 21.0 \times \text{Age (y)}$
Energy Expenditure from Activity (kcal/d)	$AEE = TEE \text{ (kcal/d)} - (TEE \times 0.1) - BMR \text{ (kcal/d)}$
Physical Activity Level	$PAL = TEE \text{ (kcal/d)} / BMR \text{ (kcal/d)}$

* BMI: Prepregnancy Body Mass Index; FM: fat mass; FFM: fat free mass; GWG: gestational weight gain; EI: energy intake; TEE: total energy expenditure; TEE_p : total energy expenditure predicted; BMR: basal metabolic rate; BMR_p : basal metabolic rate predicted; AEE: activity energy expenditure; PAL: physical activity level

Table 3

Baseline characteristics

Characteristic	Low + Ideal Gainers (n=26)	Excess Gainers (n=19)	p-value
Maternal Age, years *	31.9 ± 4.8	30.3 ± 2.8	0.21
Preconception BMI, kg/m ²	21.5 ± 2.1	25.8 ± 4.0	<0.001
Menarche Age, years	12.5 ± 1.2	12.8 ± 1.5	0.44
Maternal Education, years	17.3 ± 2.5	16.6 ± 1.6	0.31
Gravidity †			0.15
0	9 (34.6)	10 (52.6)	
1	10 (38.5)	3 (15.8)	
2	3 (11.5)	5 (26.3)	
3	3 (11.5)	0 (0.0)	
4	1 (3.9)	1 (5.3)	
Parity			0.66
0	14 (53.9)	12 (63.2)	
1	10 (38.5)	5 (26.3)	
2	2 (7.7)	2 (10.5)	
Maternal Race			0.51
White	22 (84.6)	15 (79.0)	
African American	1 (3.9)	1 (5.3)	
Hispanic	1 (3.9)	3 (15.8)	
Asian	2 (7.7)	0 (0.0)	
Income ‡			0.83
<\$20,000	1 (4.0)	0 (0.0)	
\$20,000 – \$34,999	1 (4.0)	2 (10.5)	
\$35,000 – 49,000	2 (8.0)	2 (10.5)	
\$50,000	21 (84.0)	15 (79.0)	

* Continuous variables (maternal age, BMI: body mass index, menarche age, and education) data presented as mean ± SD and p-value from two-sample t-test. Bolded p-values are p<.05.

† Categorical variable (gravidity, parity, race, and income) data presented as count (percentage) and p-value from Fisher's exact test (chi-squared).

‡ One subject in the low + ideal gainer group missing income data

Table 4

Body composition and metabolism changes throughout pregnancy *

Variable	Low + ideal gainers (n=26)	High gainers (n=19)	p-value
Weight gain, kg	10.9 ± 0.8	18.7 ± 0.7	<0.001
FM, kg	2.2 ± 1.6	9.1 ± 0.8	<0.001
FFM, kg	7.8 ± 1.5	9.2 ± 0.7	0.39
EI, kcal/d	2687 ± 110	3437 ± 99	<0.001
TEE, kcal/d	2656 ± 98	3028 ± 88	0.008
TEE _p , kcal/d	2646 ± 36	2976 ± 32	0.73
BMR, kcal/d	1681 ± 47	1913 ± 43	0.001
BMR _p , kcal/d	1547 ± 23	1762 ± 21	<0.001
AEE kcal/d	-150 ± 70	-230 ± 92	0.49
PAL	-0.26 ± 0.05	-0.31 ± 0.07	0.61

* Variables reported as Mean ± SE. Bolded p-values are p<.05. BMI: Prepregnancy Body Mass Index; FM: fat mass; FFM: fat free mass; EI: energy intake at 36 weeks of gestation; TEE: total energy expenditure at 36 weeks of gestation; TEE_p: total energy expenditure predicted (see Table 2); BMR: basal metabolic rate at 36 weeks of gestation; BMR_p: basal metabolic rate predicted (see Table 2); AEE: change in activity energy expenditure throughout pregnancy (preconception through 36 weeks of gestation); PAL: change in physical activity level throughout pregnancy (preconception through 36 weeks of gestation).