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Dietary energy density but not glycemic load is associated with gestational weight gain

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Abstract

Background—The majority of pregnant women are gaining outside of the recommended weight gain ranges. Excessive weight gains have been linked to pregnancy complications and long term maternal and child health outcomes.

Objective—To examine the impact of dietary glycemic load and energy density on total gestational weight gain and weight gain ratio (observed weight gain/expected weight gain).

Design—Data are from 1231 women with singleton pregnancies who participated in the Pregnancy, Infection, and Nutrition Cohort Study. Dietary information was collected at 26–29 weeks gestation using a semi-quantified food frequency questionnaire. Linear regression models were used to estimate the associations between glycemic load (in quartiles) and energy density (in quartiles) with total gestational weight gain and weight gain ratio.

Results—Dietary patterns of pregnant women significantly differed across many sociodemographic and behavioral characteristics, with the greatest contrasts seen for glycemic load. After adjustment for covariates, in comparison to women in the first quartile, consuming a mean dietary energy density of 0.77 kcal/g (reference), women in the second quartile, consuming a mean energy density of 0.95 kcal/g, gained an excess of 0.91 kg (95% CI: 0.02–1.79) and women in the third quartile, consuming a mean energy density of 1.09 kcal/g, gained an excess of 1.47 kg (95% CI: 0.58–2.36). All other comparisons of energy intakes were not statistically significant. Glycemic load was not associated with total gestational weight gain or weight gain ratio.

Conclusions—Dietary energy density is a modifiable factor that may assist pregnant women in managing gestational weight gains.

Keywords

Pregnancy; Diet; Gestational Weight Gain; Glycemic Load; Energy Density

INTRODUCTION

Studies have shown that a majority of women gain weight in excess of the recommended gestational weight gain guidelines (1,2,3,4,5), established by the Institute of Medicine (IOM) in 1990 (6). Although health care provider advice (7,8), psychosocial factors (9), physical

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activity, and smoking (10) have been found to influence gestational weight gain, an inability to properly adjust dietary patterns may also be a determinant of inappropriate weight gain during pregnancy.

There is currently little information on the effect of dietary intake on gestational weight gain and whether women who gain within the appropriate weight range have different dietary patterns than women who gain weight outside of the IOM recommendations (28–40 pounds for prepregnancy BMI <19.8 kg/m^2; 25–35 pounds for BMI 19.8–26.0 kg/m^2; 15–25 pounds for BMI >26.0–29.0 kg/m^2; and at least 15 pounds for BMI >29.0 kg/m^2). A recent observational study in Iceland showed that women with excessive gestational weight gains (>18 kg for normal weight women and >12 kg for overweight/obese women) were more likely to eat more sweets early in pregnancy and drink more milk as well as more food late in pregnancy, compared to women with suboptimal (<12.1 kg for normal weight women and <7.1 for overweight/obese women) and optimal (12.1–18.0 kg and 7.1–12 kg for overweight/obese women) gestational weight gains (11). Additionally, results from the Stockholm Pregnancy and Weight Development Study showed that women who expressed an increased interest in sweets during pregnancy experienced 1–2 kg greater weight gains compared to the other women in the study (12).

Two dietary characteristics thought to be associated with body weight/fat in the non-pregnancy state are energy density (13,14) and glycemic load (15). Energy density (calories/gram of food consumed) is viewed as a main contributor to overeating in the American population; increased energy density is linked with less satiety per gram of food (16,17,18) and is a key regulator of food intake regardless of the amount of calories consumed (19). The glycemic load is a measure of both dietary glycemic index and amount of carbohydrate intake, which is used to assess the glycemic response of foods. It is a common component of several popular diets and has been associated with weight loss in some studies (20,21,22). Currently, there is little research on the effects of energy density or glycemic load on gestational weight gain.

The present study uses data collected from the Pregnancy, Infection, and Nutrition Study to examine the effects of energy density and glycemic load on gestational weight gain. It is hypothesized that total gestational weight gain and the weight gain ratio increase with increasing energy density and glycemic load.

MATERIALS AND METHODS

Study Population

The data for this analysis was taken from the third cohort of the Pregnancy, Infection, and Nutrition (PIN) Study, described elsewhere (23). Briefly, the PIN Study is a longitudinal, prospective investigation of adverse birth outcomes being conducted at selected prenatal clinics in central North Carolina. Women attending their second prenatal visit who were no more than 20 weeks' gestation, at least 16 years old, carrying a singleton fetus, planning to continue care at the clinics, and had access to a telephone were eligible to participate. Women in this analysis were recruited from January 1, 2001 to June 30, 2005. A total of 2006 women were recruited of which 1773 had pregravid BMI and weight gain information available for this analysis. Some women were recruited into the cohort more than once due to additional pregnancies within the recruitment period; for the current analysis, information from only one of the pregnancies from each woman was used (n=82 excluded pregnancies). In these instances, the pregnancy with the most complete information or the first pregnancy (when information was complete for both pregnancies) was included in the analysis. Pregnancies that did not result in a live birth (n=13) and women with missing (n=396) or implausible (n=51) dietary information were also excluded. The remaining 1231 pregnancies were used in this analysis. In total, data from 542 pregnancies in the initial sample were excluded from this analysis. In comparison to women who were included, higher proportions of excluded women were less than 24 years old, obese, black, not married, low income, low education, and smokers.

The PIN study protocols were reviewed and approved by the Institutional Review Boards of the School of Medicine at the University of North Carolina at Chapel Hill and Wake Medical Center. Information on pre- and perinatal factors including sociodemographic characteristics and medical history were assessed by interviews, self-administered questionnaires, and information from medical records. Medical charts were abstracted for all women in the cohort to collect data on reproductive history, weight gain, pregnancy complications, and labor and delivery events.

Assessment of Primary Outcomes

Gestational weight gain was defined as the difference between each woman's pregravid weight, which was self-reported at the time of the first prenatal clinic visit, and her weight measured near the time of delivery. Weight measurements taken at the first prenatal clinic visit were compared to the self-reported pregravid weights to identify biologically implausible weight gains. Women with implausible values had their pregravid weight imputed following previously published methodology (1,23). Pregravid body mass index (BMI, kg/m^2) was then calculated using imputed pregravid weight and measured height.

Weight gain ratio, according to pregravid BMI status, was calculated as a ratio of observed total weight gain over expected total weight gain up until the last prenatal visit using the weight gain recommendations from the 1990 IOM report as previously described (1,23,24). To calculate expected weight gain the following formula was used: expected first trimester total weight gain + [(gestational age at time of last weight measurement-13 weeks) × rate of weight gain expected for the second and third trimesters]. The expected total first trimester weight gains were 3.2, 2.2, 1.0, and 0.5 kg and the rates were 0.5, 0.4, 0.3, and 0.23 kg/wk for underweight, normal weight, overweight, and obese women, respectively (6). These rates adjust for the fact that not all women have a weight measurement at the time of delivery. Cut points to determine inadequate and excessive weight gains were based on the IOM BMI-specific recommendations. For example, it is recommended that underweight women gain between 12.5 and 18.0 kg, which corresponds to a ratio of 75% to 110% if the pregnancy is carried to term (40 weeks). Thus, underweight women who have a ratio greater than 1.10 would be defined as gaining above the IOM recommendation (excessive) and those who have a ratio less than 0.75 would be defined as gaining below the IOM recommendation (inadequate).

Assessment of Primary Exposures

Information on diet during the second trimester was collected at 26–29 weeks gestation via a self-administered 110-item Block-98 food frequency questionnaire (FFQ), which was modified to include local foods and focus on a three month time frame as well as solicit information concerning portion sizes using a serving size visual. This FFQ was validated in several populations (25,26), including the PIN study. The validity was assessed among 99 women in PIN 1 and 82 women in PIN 2 by comparing the nutrient results from the FFQ with three 24-hour dietary recalls collected at random or on non-consecutive days. The deattenuated Pearson correlation coefficients between the FFQ and the 24-hour recalls for total energy and carbohydrates were 0.32 and 0.44, respectively, for PIN 1 and 0.33 and 0.61, respectively, for PIN 2. The FFQs were analyzed using Dietsys+Plus, version 5.6 (27). The food composition table for Dietsys was updated with nutrient values based on data from NHANES III and from the USDA's 1998 nutrient database (28).

Daily energy intakes in kilocalories and grams were calculated. The number of grams consumed included grams derived from all foods and beverages (grams contributed by water and other non-caloric beverages were excluded from analyses). Daily energy density (the amount of energy per gram of food consumed) was calculated by dividing daily kilocalories by daily grams. Daily energy densities were calculated for food alone, calorie-containing beverages alone, and food and calorie-containing beverages combined.

Glycemic index values were applied to the FFQ data by the Department of Nutrition's Clinical Research Unit Epidemiology Core using published values (29). Approximately 25% of the questions on the FFQ contained a single food that has a direct match to published values. However, as is often the case in FFQs, there were a number of mixed foods as well as those combined in a single line. One glycemic index value was derived in those situations through calculations that were proportional to the number of foods embedded in each question. From this, the average glycemic index (the average of the glycemic indices for the foods consumed regularly) and glycemic load (the product of the glycemic index and the carbohydrate content of the foods contributing to it) were calculated.

Physical Activity Assessment

Data on physical activity patterns was collected by interviewer-administered questionnaires at 17–22 and 27–30 weeks and were designed to capture moderate and vigorous activity in the past week. The questionnaire assessed frequency and duration of all moderate and vigorous physical activities including: activity done at work, recreation, for transportation, childcare, adult care, and both indoor and outdoor household activities. Intensity of activity was assessed using a modified Borg scale (30) to capture the participant's perception of intensity (metabolic equivalents, METs).

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Statistical Methods

The final analyses were conducted with the information from 1231 women using Stata version 9.2 (31). Variables were assessed as both effect modifiers and confounders. None of the variables were found to be significant effect modifiers. In order to be included in the analysis as a confounder, variables must have met the following criteria: associated with the exposure ($p \leq 0.15$), associated with the outcome ($p \leq 0.15$), and at least +/−10% change in beta coefficient when included individually in the regression models. The influence of individual and collective measurements of physical activity during the second and third trimesters (in MET hours/week and hours/week) on the association of gestational weight gain with glycemic load and energy density was examined. Only second trimester recreational physical activity was identified as a confounder of the association of weight gain ratio with both energy density and glycemic load and was included in multivariate regression models as a continuous variable (MET hours/week). Daily energy intake was regressed on glycemic load to create a residual of energy intake (the part of energy intake not explained by glycemic load). All models that included glycemic load values were adjusted for residual energy intakes. Similarly, models that included energy density were adjusted for energy intake using a residual of energy intake that was created by regressing energy intake on energy density (the part of energy intake not explained by energy density). This method was chosen so that the glycemic load and energy density variables could be directly interpreted.

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Glycemic load was evaluated in models as a continuous variable, dichotomous variable (using a cut point of >165 to designate "high intake" as previously used by Salmeron et. al. (32)), and in quartiles. Energy density was evaluated as both a continuous variable and in quartiles. T-tests of means, analysis of variances, and tests of linear trend were used to examine glycemic load and energy density across sociodemographic strata. Tests of linear trend used variables in their continuous forms. The association of glycemic load and energy density with the two main outcome variables, total gestational weight gain and weight gain ratio, were modeled by

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linear regression. The residuals for all linear regression models were assessed for normality using both a Q-Q plot of the residuals and an RXP plot comparing residuals to predicted values.

RESULTS

The mean total gestational weight gains in this population were 15.4 (SD: 4.4), 16.6 (SD: 5.3), 15.5 (SD: 6.2), and 12.0 (SD: 7.1) kg for underweight, normal weight, overweight, and obese women, respectively. The mean weight gain ratio (observed/expected gestational weight gain) was 1.51 (SD: 0.79), with means of 0.99 (SD: 0.27), 1.38 (SD: 0.43), 1.85 (SD: 0.73), and 2.01 (SD: 1.25) for underweight, normal weight, overweight, and obese women, respectively. The mean energy intake for the study population was 2162.0 kcal (SD: 713.1), the mean glycemic load was 133.3 (SD: 49.2), and the mean energy density was 1.04 (SD: 0.24). Energy density was not significantly correlated with total gestational weight gain or weight gain ratio ($r=0.05$ and 0.03, respectively). Similarly glycemic load was not correlated with total gestational weight gain ($r=-0.01$) but was significantly correlated with weight gain ratio ($r=0.07$, $p=0.02$).

Table 1 shows the distribution of the study population by selected sociodemographic characteristics and the mean energy density and glycemic load values for these characteristics. Dietary energy density was calculated in three ways: foods alone, caloric beverages alone, and foods and caloric beverages combined. Only the energy densities derived from foods and caloric beverages combined were significantly associated with gestational weight gain and are presented here. Dietary energy densities did not differ among women for all of the selected characteristics with the exception of maternal smoking within the first 6 months of pregnancy; smokers reported diets with lower energy densities compared to non-smokers, 0.99 and 1.05, respectively ($p=0.01$). Additionally, there was a positive relationship between energy density and education, with more educated women eating diets higher in energy density compared to less educated women (p for trend=0.01) and between energy density and recreational physical activity during the second trimester (p for trend=0.04).

In contrast to energy density, mean dietary glycemic load significantly differed across all of the sociodemographic characteristics with the exception of IOM weight gain adequacy categories. A significant positive trend was observed for mean glycemic load with pregravid BMI (p for trend=0.001) and significant inverse trends were observed for mean glycemic load with education (p for trend<0.001), family income (p for trend<0.001), maternal age (p for trend<0.001), and recreational physical activity during the first and second trimesters (p for trend= 0.02 and 0.05, respectively). The highest mean glycemic loads were found among women who were unmarried, black, aged 16–24 years, had a high school education or less, had a family income less than 185% poverty, and self-reported smoking within the first 6 months of pregnancy.

Table 2 shows the crude and adjusted associations of total gestational weight gain and weight gain ratio with quartiles of energy density. The crude values differ slightly from their respective adjusted values; however, the statistical significance of the values remains the same after adjustment. In comparison to women in the first quartile, consuming a mean dietary energy density of 0.77 kcal/g (reference), women in the second quartile, consuming a mean energy density of 0.95 kcal/g, gained an excess of 0.91 kg (95% CI: 0.02–1.79); women in the third quartile, consuming a mean energy density of 1.09 kcal/g, gained an excess of 1.47 kg (95% CI: 0.58–2.36); and women in the fourth quartile, consuming a mean energy density of 1.37 kcal/g, gained an excess of 0.87 kg (95% CI: −0.02, 1.76). Women in the second and third quartiles gained significantly ($P<0.05$) more weight compared to women in the first quartile. On average, women in the first, second, third, and fourth quartiles gained 14.30 (SD: 5.94), 15.40 (SD: 5.83), 16.41 (SD: 5.57), and 15.13 (SD: 6.48) kg, respectively. There were no significant associations between energy density and weight gain ratio. Regardless of energy density intake, women gained in excess of the IOM guidelines; the weight gain ratios of women in the first, second, third, and fourth quartiles were 1.44 (SD:0.72), 1.55 (SD:0.81), 1.51 (SD: 0.71), and 1.55 (SD:0.92), respectively. Energy density was also modeled as a continuous variable but was not associated with either of the gestational weight gain outcomes (data not shown).

Table 3 shows the crude and adjusted associations of total gestational weight gain and weight gain ratio with quartiles of glycemic load. Glycemic load was not associated with either gestational weight gain outcome both before and after adjustment for model-specific covariates, with the exception that there was a significant crude association for the fourth quartile of glycemic load and weight gain ratio. On average, women in the first, second, third, and fourth quartiles gained 15.21 (SD: 6.04), 15.70 (SD: 5.53), 15.09 (SD: 5.98), and 15.25 (SD: 6.44) kg, respectively. The weight gain ratios for each quartile were 1.49 (SD: 0.79), 1.47 (SD: 0.71), 1.43 (SD: 0.71), and 1.66 (SD: 0.93), respectively. Glycemic load was also modeled as a continuous variable and a dichotomous variable using a cut point of 165; however, it was still not associated with gestational weight gain (data not shown).

DISCUSSION

This analysis is among the first to explore the potential influence of dietary glycemic load and energy density on gestational weight gain. The main findings of the analysis are the following: 1) Dietary patterns of pregnant women were found to significantly differ across many sociodemographic and behavioral characteristics, with the greatest contrasts seen for glycemic load; 2) Dietary energy density was significantly associated with total gestational weight gain but not with weight gain ratio (observed/expected weight gain); 3) Dietary glycemic load was not associated with either outcome of gestational weight gain; and 4) Mean energy density and glycemic load values did not significantly differ across IOM gestational weight gain categories (Table 1).

Cross sectional studies have demonstrated a positive association between energy density and body weight, with individuals who report lower energy dense diets having lower body weights than those who report higher energy dense diets (33,34). In the laboratory setting, low energy dense meals have been shown to decrease energy intakes and increase satiety compared to high energy dense meals (19,35,36). The results from the current analysis are consistent with these findings; energy intakes increased across quartiles of energy density, with mean energy intakes of 1915, 2100, 2251, and 2381 kcals for women in the first, second, third, and fourth quartiles, respectively. Women who reported consuming higher dietary energy density during the second trimester of pregnancy had greater gestational weight gains compared to women consuming the lowest dietary energy density, independent of energy intake. Despite this association, energy density was not associated with weight gain ratio. This may be attributable to the fact that nearly two-thirds of the study population had weight gains that exceeded the IOM recommendations and that the amount of weight gain associated with dietary energy density was modest (less than 2 kg); therefore, differences in weight gain ratios were small and did not reach statistical significance.

In this analysis there was a positive association between pregravid BMI and glycemic load, with obese women consuming diets with the highest glycemic load values; though there was no association between glycemic load and gestational weight gain once we adjusted for confounding. Studies examining the impact of both glycemic index and load on body weight have yielded mixed results with positive associations for both glycemic index and load (37), glycemic index alone (38), as well as no association for either measure (39). Thirty percent calorie-restricted diets of high and low glycemic loads have shown comparable effects on weight loss (40), which suggests that energy intake may completely explain the relationship between glycemic index and load and body weight/fatness. However, a recent systematic review of six randomized controlled trials found that overweight or obese individuals lost more body mass and total fat mass on low glycemic index or load diets compared to those on control diets, regardless of energy restriction (41). Many of the studies that have examined the association between body weight and glycemic index/load have differed in type, length, size, diet composition, manipulation of glycemic index or load, and source population characteristics (such as age and BMI status), which makes it difficult to understand the true association and what, if any, effect measure modifiers exist.

Currently, there is little information in the literature regarding the impact of glycemic load on gestational weight gain. Data from the Camden Study (Camden, New Jersey), which used a cohort of young, racially diverse, low-income, non-diabetic pregnant women, found that high maternal serum insulin concentrations were associated with greater gestational weight gain and postpartum weight retention (42). Yet analyses from this cohort did not find an association between dietary glycemic index (the average of three 24-hour recalls) and rate of weight gain (kg/wk) or adequacy of weight gain (43). Despite the lack of evidence for an association between dietary glycemic load and gestational weight gain, glycemic load has been shown to effect fetal growth (44) and the development of gestational diabetes (44), as well as other non-pregnancy related health conditions. The current analysis revealed several sociodemographic and behavioral characteristics that are associated with high glycemic load diets within a population of pregnant women, specifically, maternal age, race, education, income, marital status, parity, smoking status, and recreational physical activity. This information may prove useful when designing dietary interventions targeted to pregnant women.

One limitation of this study is the use of an FFQ to measure dietary glycemic load and energy density since FFQs are not specifically designed to capture these aspects of the diet. Glycemic load may be difficult to measure with an FFQ due to the inability to accurately assess combinations and portions of foods, both in recipes and during meals, which can impact the overall glycemic effect and carbohydrate amounts of the foods. Measurement of glycemic load via FFQs has been validated in previous studies, which have shown that nutrient intakes assessed by standardized FFQs are reasonably correlated with those from more detailed methods and provide a valid representation of usual intake for ranking subjects (45,46,47). Similarly, the ascertainment of energy density from FFQs has been validated against multiple 24-hour recalls and found to be an acceptable measure of energy density (48). Additionally, the original Block questionnaire was validated in a variety of populations and the modified version used in the PIN study was validated in previous PIN cohorts; therefore, we are confident that both glycemic load and energy density were at least reasonably measured by our FFQ.

Another limitation is that pregravid weights were self-reported. Although self-reported weights have been shown to be reliable there is a tendency for overweight and obese women to underestimate their weights (49,50,51). Considering that approximately a third of the study population reported being overweight or obese prior to pregnancy, underestimation of pregravid weight may have resulted in an overestimation of gestational weight gains. This bias was likely to have been attenuated by the imputation of pregravid weights when implausible weight gains were found between the self-reported weights and clinically measured weights recorded during the first prenatal visits; however, any bias that remained may have exaggerated the association between energy density and gestational weight gain.

The results from this analysis provide practical information regarding the influence of glycemic load and energy density on gestational weight gain. Glycemic load was not associated with gestational weight gain in this population but was associated with several sociodemographic and behavioral characteristics. Increasing dietary energy density was associated with greater energy intakes and total gestational weight gain, but not weight gain ratio. Both energy density and glycemic load may prove to be useful modifiable dietary factors in guiding women to choose nutritious foods, such as fruits, vegetables, and whole grains, and to promote overall health throughout pregnancy; however, neither factor appears to be sufficient for helping women achieve appropriate weight gains. Future research may seek to investigate dietary patterns and specific food groups as well as other behavioral characteristics that are associated with gestational weight gains within the IOM recommendations.

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References

1. Siega-Riz AM, Adair LS, Hobel CJ. Institute of Medicine maternal weight gain recommendations and pregnancy outcome in a predominantly Hispanic population. Obstet Gynecol 1994;84:565–573. [PubMed: 8090394]
2. Carmichael S, Abrams BA, Selvin S. The pattern of maternal weight gain in women with good pregnancy outcomes. Am J Public Health 1997;87:1984–1988. [PubMed: 9431288]
3. Schieve LA, Cogswell ME, Scanlon KS. Trends in pregnancy weight gain within and outside ranges recommended by the Institute of Medicine in a WIC population. Maternal and Child Health Journal 1998;2(2):111–116. [PubMed: 10728266]
4. Cogswell ME, Scanlon KS, Fein SB, et al. Medically advised, mother's personal target, and actual weight gain during pregnancy. Obstet Gynecol 1999;94:616–622. [PubMed: 10511369]
5. Dietz PM, Callaghan WM, Cogswell ME, Morrow B, Ferre C, Schieve LA. Combined effects of prepregnancy body mass index and weight gain during pregnancy on the risk of preterm delivery. Epidemiology 2006;17(2):170–177. [PubMed: 16477257]
6. Institute of Medicine. Part I, weight gain. Washington, DC: National Academy Press; 1990. Nutrition during pregnancy.
7. Stotland NE, Haas JS, Brawarsky P, Jackson RA, Fuentes-Afflick E, Escobar GJ. Body Mass Index, Provider Advice, and Target Gestational Weight Gain. Obstet Gynecol 2005;105:633–638. [PubMed: 15738036]
8. Cogswell ME, Scanlon KS, Fein SB, et al. Medically advised, mother's personal target, and actual weight gain during pregnancy. Obstet Gynecol 1999;94:616–622. [PubMed: 10511369]
9. Strychar IM, Chabot C, Champagne F, et al. Psychosocial and lifestyle factors associated with insufficient and excessive maternal weight gain during pregnancy. JADA 2000;100 (3):353–356.
10. Olson CM, Strawderman MS. Modifiable behavioral factors in a biopsychosocial model predict inadequate and excessive gestational weight gain. JADA 2003;103:48–54.
11. Olafsdottir AS, Skuladottir GV, Thorsdottir I, Hauksson A, Steingrimsdottir L. Int J Obes (Lond) 2006;30(3):492–499. [PubMed: 16331301]
12. Ohlin A, Rossner S. Factors related to body weight changes during and after pregnancy: the Stockholm Pregnancy and Weight Development Study. Obes Res 1996;4 (3):271–276. [PubMed: 8732961]
13. Moore MS. Interactions between physical activity and diet in the regulation of body weight. Proc Nutrition Society 2000;59(2):193–198.
14. Stubbs J, Ferres S, Horgan G. Energy density of foods: effects on energy intake. Critical Reviews in Food Science & Nutrition 2000;40(6):481–515. [PubMed: 11186237]
15. Ludwig DS, Majzoub JA, Al-Zahrani A, Dallal GE, Blanco I, Roberts SB. High glycemic index foods, overeating, and obesity. Pediatrics 1999;103(3):E26. [PubMed: 10049982]

16. Drewnowski A. Energy density, palatability, and satiety: implications for weight control. Nutr Rev 1998;56:347–353. [PubMed: 9884582]
17. Rolls BJ, Kim-Harris S, Fischman MW, Foltin RW, Moran TH, Stoner SA. Satiety after preloads with different amounts of fat and carbohydrate: implications for obesity. Am J Clin Nutr 1994;60:476–487. [PubMed: 7661908]
18. Blundell JE, Macdiarmid JI. Passive overconsumption. Fat intake and short-term energy balance. Ann NY Acad Sci 1997;827:392–407. [PubMed: 9329770]
19. Bell EA, Castellanos VH, Pelkman CL, Thorwart ML, Rolls BJ. Energy density of foods affects energy intake in normal weight women. Am J Clin Nutr 1998;67:412–420. [PubMed: 9497184]
20. Price, J.; Brand-Miller, J.; O'Neill, K.; Petocz, P. The effects of 4 diets varying in glycemic load, carbohydrate, and protein content, on weight loss and body composition. Proceedings of the Australian Society for the Study of Obesity 12th Annual Scientific Meeting; 2004.
21. Spengler, M.; Boehme, K. Tolerance and Acceptance of Isomalt. Study 26. Wuppertal, Germany: Bayer AG Pharmaceuticals Division; 1984. Report no. 13850
22. Ebbeling CB, Leidig MM, Sinclair KB, Hangen JP, Ludwig DS. A reduced glycemic load diet in the treatment of adolescent obesity. Archives of Pediatrics and Adolescent Medicine 2003;157:773–779. [PubMed: 12912783]
23. Vahratian A, Zhang J, Troendle JF, Savitz DA, Siega-Riz AM. Maternal prepregnancy overweight and obesity and the pattern of labor progression in term nulliparous women. Obstet Gynecol 2004;104 (5 Pt 1):943–951. [PubMed: 15516383]
24. Bodnar LM, Siega-Riz AM, Arab L, Chantala K, McDonald T. Predictors of pregnancy and postpartum haemoglobin concentrations in low income women. Public Health Nutr 2004;7(6):701–711. [PubMed: 15369607]
25. Block G, Thompson FE, Hartman AM, Larkin FA, Guire KE. Comparison of two dietary questionnaires validated against multiple dietary records collected during a 1-year period. Am J Diet Assoc 1992;92:686–693.
26. Block G, Hartman AM, Dresser CM, Carroll MD, Gannon J, Gardner L. A data based approach to diet questionnaire design and testing. Am J Epidemiol 1986;124:453–469. [PubMed: 3740045]
27. Dietsys +Plus Analysis Software, Version 5.6, Block Dietary Data Systems, 1999.
28. US Department of Agriculture. USDA nutrient data base for standard reference, release #12. Riverdale, MD: Agriculture Research Service; 1998.
29. Foster-Powell K, Brand-Miller J. International tables of glycemic index. Am J Clin Nutr 1995;62:871S–890S. [PubMed: 7572722]
30. Borg G, Linderholm H. Perceived exertion and pulse rate during graded exercise in various age groups. Acta Med Scand 1974;472:194–206.
31. STATA [computer program]. Version 9.2. College Station, TX: Stata Corp;
32. Salmeron J, Manson JE, Stampfer MJ, Colditz GA, Wing AL, Willett WC. Dietary fiber, glycemic load, and risk of non-insulin-dependent diabetes mellitus in women. JAMA 1997;277:472–477. [PubMed: 9020271]
33. Ledikwe JH, Blanck HM, Khan LK, et al. Dietary energy density is associated with energy intake and weight status in US adults. Am J Clin Nutr 2006;83:1362–1368. [PubMed: 16762948]
34. Kant AK, Graubard BI. Energy density of diets reported by American adults: association with food group intake, nutrient intake, and body weight. Int J Obesity 2005;29:950–956.
35. Duncan KH, Bacon JA, Weinsier RL. The effects of high and low energy density diets on satiety, energy intake, and eating time of obese and non-obese subjects. Am J Clin Nutr 1983;37:763–767. [PubMed: 6303104]
36. Kral TVE, Roe LS, Rolls BJ. Combined effects of energy density and portion size on energy intake in women. Am J Clin Nutr 2004;79:962–968. [PubMed: 15159224]
37. Lau C, Toft U, Tetens I, et al. Association between dietary glycemic index, glycemic load, and body mass index in the Inter99 Study: is underreporting a problem. Am J Clin Nutr 2006 Sept;84(3):641–645. [PubMed: 16960180]
38. Ma Y, Olendzki B, Chiriboga D, et al. Association between dietary carbohydrates and body weight. Am J Epidemiol 2005;161(4):359–367. [PubMed: 15692080]

39. Liese AD, Schulz M, Fang F, et al. Dietary Glycemic index and glycemic load, carbohydrate and fiber intake, and measures of insulin sensitivity, secretion, and adiposity in the insulin resistance atherosclerosis study. Diabetes Care 2005;28:2832–2838. [PubMed: 16306541]

40. Das SK, Gilhooly CH, Golden JK, et al. Long-term effects of 2 energy restricted diets differing in glycemic load on dietary adherence, body composition, and metabolism in CALERIE: a 1-y randomized controlled trial. Am J Clin Nutr 2007;85(4):1023–1030. [PubMed: 17413101]

41. Thomas DE, Elliot EJ, Baur L. Low glycaemic index or load diets for overweight and obesity. Cochrane Database of Systematic Reviews 2007. (3)10.1002/14651858.CD005105.pub2Art. No.: CD005105

42. Scholl TO, Chen X. Insulin and the “thrifty” woman: the influence of insulin during pregnancy on gestational weight gain and postpartum weight retention. Matern Child Health J 2002;6 (4):255–261. [PubMed: 12512767]

43. Scholl TO, Chen X, Khoo CS, Lenders C. The dietary glycemic index during pregnancy: influence on infant birth weight, fetal growth, and biomarkers of carbohydrate metabolism. Am J Epidemiol 2004;159 (5):467–474. [PubMed: 14977642]

44. Zang C, Liu S, Solomon CG, Hu FB. Dietary Fiber Intake, Dietary Glycemic Load, and the Risk for Gestational Diabetes Mellitus. Diabetes Care 2006;29:2223–2230. [PubMed: 17003297]

45. Levitan EB, Westgren CW, Liu S, Wolk A. Reproducibility and validity of dietary glycemic index, dietary glycemic load, and total carbohydrate intake in 141 Swedish men. Am J Clin Nutr 2007;85 (2):548–553. [PubMed: 17284756]

46. Willet W. Nutritional epidemiology issues in chronic disease at the turn of the century. Epidemiol Rev 2000;22:82–86. [PubMed: 10939011]

47. Barclay AW, Flood VM, Brand-Miller JC, Mitchell P. Validity of carbohydrate, glycaemic index and glycaemic load data obtained using a semi-quantitative food frequency questionnaire. Public Health Nutrition 2007 Oct 24;:1–8.

48. Howarth NC, Murphy SP, Wilkens LR, Hankin JH, Kolonel LN. Dietary energy density is associated with overweight status among 5 ethnic groups in the multiethnic cohort study. J Nutr 2006;136(8): 2243–2248. [PubMed: 16857848]

49. Brunner Huber LR. Validity of self-reported height and weight in women of reproductive age. Matern Child Health J 2007;11:137–144. [PubMed: 17066316]

50. Engstrom JL, Paterson SA, Doherty A, Trabulsi M, Speer KL. Accuracy of self reported height and weight in women: An integrative review of the literature. J Midwifery and Women’s Health 2003;48 (5):338–345.

51. Rowland ML. Self Reported weight and height. Am J Clin Nutr 1990;52:1125–1133. [PubMed: 2239790]

TABLE 1

Baseline distributions of sociodemographic and behavioral characteristics according to mean dietary energy density and glycemic load in the Pregnancy, Infection, and Nutrition Cohort Study (N=1231)

Characteristic	n	Frequency (%)	Mean Energy Density (SD)	P[1]	Mean Glycemic Load (SD)	P[1]
Weight Gain Adequacy[3]						
Inadequate	167	13.6	1.03 (0.26)	0.55	133.16 (49.83)	0.11
Adequate	273	22.2	1.04 (0.24)		129.64 (45.33)	
Excessive	791	64.2	1.05 (0.24)		134.65 (50.39)	
P for trend[2]				0.32		0.41
Maternal Age at Conception (years)						
16–24	229	18.6	1.04 (0.29)	0.89	159.54 (63.75)	<0.001
25–29	355	28.8	1.04 (0.23)		129.55 (45.26)	
30–34	438	35.6	1.05 (0.23)		128.85 (42.54)	
35–47	209	17.0	1.03 (0.25)		120.45 (40.03)	
P for trend[2]				0.57		<0.001
Pregravid BMI[4]						
Underweight	176	14.3	1.07 (0.25)	0.47	135.01 (47.79)	<0.001
Normal	652	53.0	1.04 (0.23)		128.12 (43.92)	
Overweight	126	10.2	1.04 (0.27)		135.82 (51.89)	
Obese	277	22.5	1.03 (0.26)		143.42 (58.44)	
P for trend[2]				0.19		0.001
Maternal Race						
White	917	74.5	1.04 (0.23)	0.92	128.27 (43.79)	<0.001
Black	199	16.2	1.04 (0.26)		160.31 (62.49)	
Other	115	9.3	1.03 (0.27)		127.02 (49.47)	
Marital Status						
Married	971	78.9	1.05 (0.23)	0.46	127.14 (43.55)	<0.001
Other	259	21.1	1.03 (0.28)		156.44 (61.16)	
Maternal Education						
≤Grade 12	215	17.5	1.02 (0.28)	0.18	160.08 (66.45)	<0.001
Grades 13–16	584	47.4	1.05 (0.24)		131.15 (46.03)	
≥Grade 17	432	35.1	1.05 (0.22)		122.98 (37.28)	
P for trend[2]				0.01		<0.001
Family Income (% 2001 Poverty Index)						
<185%	220	18.5	1.05 (0.28)	0.10	158.55 (63.18)	<0.001
185–350%	222	18.7	1.01 (0.23)		139.23 (51.67)	
>350%	744	62.7	1.05 (0.23)		122.94 (38.27)	
P for trend[2]				0.15		<0.001
Parity						
Nulliparous	642	52.2	1.04 (0.24)	0.84	129.76 (47.36)	0.008
1 or more births	589	47.8	1.04 (0.24)		137.23 (50.96)	
Smoking Status[5]						
Yes	118	10.0	0.99 (0.26)	0.01	151.02 (61.61)	<0.001
No	1064	90.0	1.05 (0.24)		130.27 (46.19)	
Total Second Trimester Recreational Activity (MET hours/week)						
≤4.5	607	50.1	1.05 (0.26)	0.31	137.78 (49.59)	<0.001
> 4.5	604	49.9	1.03 (0.22)		128.01 (47.11)	
P for trend[2]				0.86		0.02
Total Third Trimester Recreational Activity (MET hours/week)						
≤4.5	626	52.8	1.05 (0.26)	0.60	135.48 (50.67)	0.01
>4.5	542	47.2	1.04 (0.22)		128.16 (44.15)	
P for trend[2]				0.04		0.05

[1] P values from ANOVA or T test of means, testing for differences across strata.

[2] Tests for trend using continuous variable.

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[3]Using IOM categories for adequacy of weight gain according to maternal pregravid BMI and gestational age (described in Methods section).

[4]According to categories established by the IOM guidelines: Underweight, BMI <19.8; Normal Weight, 19.8–26.0; Overweight, >26.0–29.0; and Obese, >29.0

[5]Self-reported smoking during months 1–6 of pregnancy.

TABLE 2

Crude and adjusted linear regression models and 95% confidence intervals (95% CI) for quartiles of energy density with total gestational weight gain and weight gain ratio in the Pregnancy, Infection, and Nutrition Cohort Study.

	Total Gestational Weight Gain (kg)[1]		Weight Gain Ratio[2]	
Quartiles of Energy Density: Mean (Range)	**Crude Beta Coefficient(95% CI)**	**Beta Coefficient[3] (95% CI)**	**Crude Beta Coefficient (95% CI)**	**Beta Coefficient[4] (95% CI)**
1: 0.77 (0.47–0.88)	Reference	Reference	Reference	Reference
2: 0.95 (0.88–1.02)	1.10 (0.16, 2.04)[5]	0.91 (0.02, 1.79)[5]	0.11 (−0.02, 0.23)	0.07 (−0.05, 0.19)
3: 1.09 (1.02–1.17)	2.11 (1.17, 3.05)[5]	1.47 (0.58, 2.36)[5]	0.07 (−0.06, 0.19)	0.12 (−0.0003, 0.24)
4: 1.37 (1.17–2.12)	0.83 (−0.11, 1.78)	0.87 (−0.02, 1.76)	0.11 (−0.01, 0.24)	0.11 (−0.01, 0.23)

[1] Linear regression analysis with total gestational weight gain (kg) as dependent variable; n=1231. Beta coefficients represent change in total gestational weight gain compared to the reference (Quartile 1).

[2] Linear regression analysis with weight gain ratio (observed weight gain/expected weight gain) as dependent variable; n=1147. Beta coefficients represent change in weight gain ratio compared to the reference (Quartile 1).

[3] Beta coefficients adjusted for pregravid BMI, gestational age, and residual energy intake.

[4] Beta coefficients adjusted for pregravid BMI, education, smoking status, third trimester recreational physical activity (MET hours/week), and residual energy intake.

[5] $P<0.05$

TABLE 3

Crude and adjusted linear regression models and 95% confidence intervals (95% CI) for quartiles of glycemic load with total gestational weight gain and weight gain ratio in the Pregnancy, Infection, and Nutrition Cohort Study.

	Total Gestational Weight Gain (kg)[1]		Weight Gain Ratio[2]	
Quartiles of Glycemic Load: Mean (Range)	Crude Beta Coefficient(95% CI)	Beta Coefficient[3] (95% CI)	Crude Beta Coefficient(95% CI)	Beta Coefficient[4] (95% CI)
1: 82.1 (36.0–98.9)	Reference	Reference	Reference	Reference
2: 112.4 (99.0–125.8)	0.48 (−0.47, 1.43)	0.27 (−0.64, 1.17)	−0.02 (−0.15, 0.10)	0.02 (−0.10, 0.14)
3: 139.2 (125.8–156.2)	−0.12 (−1.06, 0.83)	−0.10 (−1.00, 0.80)	−0.06 (−0.19, 0.06)	0.002 (−0.12, 0.12)
4: 199.8 (156.3–395.1)	0.04 (−0.91, 0.99)	0.73 (−0.21, 1.67)	0.16 (0.04, 0.29) [5]	0.11 (−0.02, 0.23)

[1] Linear regression analysis with total gestational weight gain (kg) as dependent variable; n=1186. Beta coefficients represent change in total gestational weight gain compared to the reference (Quartile 1).

[2] Linear regression analysis with weight gain ratio (observed weight gain/expected weight gain) as dependent variable; n=1111. Beta coefficients represent change in weight gain ratio compared to the reference (Quartile 1).

[3] Beta coefficients adjusted for pregravid BMI, maternal age, race, education, income, parity, gestational age, and residual energy intake.

[4] Beta coefficients adjusted for pregravid BMI, maternal age, marital status, education, income, smoking status, third trimester recreational physical activity (MET hours/week), and residual energy intake.

[5] $P<0.05$