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The pattern of gestational weight gain is associated with changes in maternal body composition and neonatal size

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Abstract

Objectives—The pattern of gestational weight gain (GWG) reflects general nutrient availability to support growing fetal and maternal compartments and may contribute to later health; but how it relates to changes in maternal body composition is unknown. We evaluated how the pattern of gestational weight gain (GWG) related to changes in maternal body composition during pregnancy and infant size at birth.

Methods—A prospective, multi-ethnic cohort of 156 pregnant women and their infants was studied in New York City. Prenatal weights were used to estimate total and rate (kg/wk) of GWG by trimester. Linear regression models evaluated the association between trimester-specific GWG group (low, medium, high GWG) [total (low≤25%ile, high≥75%ile) or rate (defined by tertiles)] and infant weight, length and maternal body composition changes from 14–37 weeks, adjusting for covariates.

Results—Compared to the low gain group, medium/high rate of GWG in the second trimester and high rate of GWG in the third trimester was associated with larger gains in maternal fat mass (β range for fat Δ=2.86–5.29 kg, all $p<0.01$) For infant outcomes, high rate of GWG in the second trimester was associated with higher birth weight (β=356 g, $p=0.001$) and length (β=0.85 cm, $p=0.002$). First and third trimester GWG were not associated with neonatal size.

Conclusions—The trimester specific pattern and rate of GWG reflect changes in maternal body fat and body water, and are associated with neonatal size, which supports the importance of monitoring trimester-specific GWG.

Keywords

Pregnancy; Body Composition; Gestational weight gain; Infant; Maternal

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Introduction

Pregnancy weight gain (GWG) is potentially modifiable and recognized as an important contributor to short- and long-term maternal and child health outcomes, including pregnancy outcomes, later obesity and metabolic health (Viswanathan et al., 2008). The Institute of Medicine (IOM) recommendations for GWG, specific to prepregnancy body mass index (BMI) group, include recommended ranges for total GWG and rate of weight gain per week for the second and third trimesters (Institute of Medicine, 2009). These guidelines, however, were established with limited evidence on how the pattern and timing of GWG influences health outcomes, and the IOM recommended future research in this area (Institute of Medicine, 2009). For example, a mother may exhibit low GWG early in pregnancy and then have rapid GWG later in pregnancy. This mother's total GWG could potentially be the same as a mother who had steady GWG—within the IOM recommendations—throughout the course of pregnancy. While these mothers exhibited the same amount of total GWG, the uterine and nutrient milieu supporting fetal growth may differ, due to the pattern of GWG, and thus differentially affect later health.

Although total weight changes are monitored during prenatal care, the components of GWG that contribute to these changes are not. During pregnancy, GWG includes increments in maternal fat mass and lean mass, which may have different implications for the health of the mother and the baby. For example, increases in maternal lean mass and body water are associated with higher infant birth weight (Butte, Ellis, Wong, Hopkinson, & Smith, 2003), while maternal fat gains are associated with greater postpartum fat retention, but not infant birth weight (Butte et al., 2003). It is less clear how specific patterns of GWG relate to changes in maternal body composition; the amount of fat mass gain, in particular, may have important implications for maternal and offspring health. The pattern and timing of GWG are associated with offspring size; greater GWG in the first (Brown, Murtaugh, Jacobs, & Margellos, 2002) and second trimester (Abrams & Selvin, 1995; Brown et al., 2002) has been associated with higher infant birth weight, while GWG in the first trimester has been associated with overweight in childhood (4). Interestingly, greater gain in the first and third trimesters, but not the second trimester, has been associated with longer birth length (Brown et al., 2002). These studies, however, have not characterized the composition of GWG.

Here we investigate how the pattern of GWG relates to changes in maternal body composition and infant size. We also evaluated how adherence to the IOM rates of weight gain in the second and third trimester relates to maternal body composition changes.

Subjects and Methods

Data are from a unique prospective cohort and includes multiple longitudinal weight measurements abstracted from the prenatal medical records, maternal body composition assessed with a four-compartment model at approximately 14 and 37 weeks of pregnancy, and newborn weight and length. The study design and primary findings were previously reported (Lederman et al., 1997, 1999; Paxton et al., 1998). Briefly, pregnant women were recruited between 1991 and 1993 from four prenatal care clinics in New York City. Women were considered eligible if they had a singleton pregnancy, were 18–35 years old, ≤16 wk gestation (based on last menstrual period), nonsmoking, and reported no HIV infection, drug/alcohol use during pregnancy, or illness requiring regular medication (such as diabetes).

Body composition and laboratory weights were obtained at approximately 14 wk gestation (range: 10–18 wk), and ≥37 wk gestation. Total body water (TBW) was estimated using a 10 g deuterated water (D_2O) dose (methods previously described (Paxton et al., 1998)). Body density was estimated with underwater weighing (Wilmore, Vodak, Parr, Girandola, & Billing, 1980). Approximately 3 weeks after delivery (range: 2 to 4 wk), total body bone mineral was measured by dual energy absorptiometry (DXA) (Lunar Radiation Corp., Madison, WI) or whole-body ^{153}Gd dual-photon absorptiometry (DP) (Lunar Radiation Corp., Madison, WI) (conversion of DP to DXA estimates has been previously described (4)). Total body fat was estimated using a four compartment model (Selinger, 1977) that sets body weight equal to the summation of fat, water, protein, bone mineral and nonosseous mineral. Body volume measured by underwater weighing was set equal to the sum of each component volume determined from its density and weight fraction in the body. Known density values were used for each component at 36°C (fat = 0.9007, water = 0.99371, protein =1.34, bone mineral = 2.982); nonosseous mineral was estimated as 1.05% of body weight (8). The following was derived from the four-compartment model volume equations (Lederman et al., 1997):

$$\%\text{fat}=\left(\frac{2.747}{\text{D}}-\frac{0.714\text{TBW}}{\text{body weight}}+\frac{1.129\text{B}}{\text{body weight}}-2.037\right)\times 100$$

where D is body density in g/mL, TBW is total body water in L, B is bone mineral in kg, and body weight is in kg. The within-subject test-retest reliability coefficient and the standard deviation for %fat estimates by the four-compartment model were 0.994 and ± 1.1, respectively (4).

Maternal age, parity, education, marital status, race/ethnicity and prepregnancy weight were obtained by self-report at screening. Self-reported prepregnancy weight was highly correlated with medical record values in these women (Lederman & Paxton, 1998). Prenatal visit weights were abstracted from medical records; weights were missing if the mother received care at a site other than the delivery hospital or if the record was misfiled. Total GWG was determined by subtracting the reported prepregnancy weight from the last measured weight in pregnancy—obtained at mean 39.1±1.7 wk gestation (range: 34–42 wk). GWG for the current study was classified as adequate, inadequate or excessive according to the Institute of Medicine 2009 guidelines for prepregnancy body mass index (BMI) categories for underweight (<18.5 kg/m^2), normal weight (18.5–<25 kg/m^2); overweight (25–<30 kg/m^2) and obese (≥ 30 kg/m^2) (Institute of Medicine, 2009). Newborn birth weight and length were obtained by abstraction of the medical record after delivery or from maternal report at the postpartum visit; no significant differences were observed between maternal report and medical record values (Lederman & Paxton, 1998).

Ethics

Written informed consent was obtained on all study participants and Institutional Review Board Approval was obtained.

Statistics

Analyses were conducted using Stata 12.0 (College Station, TX) with an α of <0.05 denoting statistical significance. To evaluate for selection bias, characteristics of the analytic sample were compared to dyads excluded from the analysis (n=44), due to missing pregnancy weight data (n=41) or missing prepregnant weight (n=3), using t-tests for continuous, normally distributed variables, and non-parametric tests for other continuous variables.

Total gain for each trimester was calculated by subtracting the last measured weight for each trimester from the end weight for the previous trimester. For those missing a weight within 1 wk of the end of each trimester, a weight was interpolated for this time by assuming linearity between measured weights obtained at prenatal or study visits. For each trimester, GWG was modeled as low, medium or high total gain (kg) and rate of gain (kg/wk), regardless of prepregnancy BMI category. For each trimester, continuous total GWG (kg) groups were defined as follows, GWG≤25%ile was low, 25.1–74.9%ile was medium, and ≥75%ile was high GWG (Table 1). GWG rate (kg/wk) groups (low, medium, high) were categorized into evenly distributed tertiles for each trimester using Stata 12.0. T-tests were used for continuous, normally distributed variables, non-parametric tests for other variables, one way analysis of variance tests for categorical variables to evaluate whether sample characteristics varied by trimester GWG, specifically rate of GWG (as this accounts for varying gestational ages in the third trimester). Pearson correlation coefficients were used to evaluate the linear association between trimester-specific total and rate of GWG.

Linear regression models evaluated the association between trimester pattern of GWG (low, medium, high) and the following dependent variables: maternal fat mass gain from 14 to 37 wk, TBW gain from 14 to 37 wk, and birth weight and length. Because prepregnancy BMI may modify the association between GWG pattern and outcomes, we used linear regression to determine if prepregnancy BMI modified this association with an α of ≤ 0.10. An interaction term between prepregnancy BMI and total GWG was retained in the birth weight model; no other significant interactions were observed. Adjusted models controlled for parity, maternal race/ethnicity, age, education, prepregnancy BMI (kg/m^2), and gestational age at birth. For maternal body composition outcomes, models included the 14 wk values for fat mass and TBW. In an additional set of linear regression models, we evaluated how adherence to the IOM guidelines for rate of GWG in the second and third trimester (Institute of Medicine, 2009) related to changes in maternal body fat and body water, controlling for prepregnancy weight and initial body composition. Effect estimates of our primary covariate of interest, GWG pattern, and effect estimates of secondary covariates (prepregnancy BMI, initial body composition) are reported; other effect estimates are not included in the tables to limit potential misunderstanding of associations (Westreich & Greenland, 2013).

Results

Weights from the women's prenatal care records were available for 159 of the 200 pregnant women enrolled in the study. Three of these women did not report prepregnancy weight, leaving an analysis sample of 156. Baseline characteristics and infant length and weight were similar between included and excluded women. Mothers included in the analysis, however, had greater total weight gain and body water gain compared to excluded women (total GWG: 15.6±6.6 kg vs. 12.8±4.5 kg, p=0.02; TBW gain: 7.3±3.0 vs. 6.0±2.5 L, p=0.01). Fat mass gain from 14 to 37 wk did not differ between those included and excluded from the analysis (3.3±4.5 vs 3.3±4.0 kg, p=0.97).

Table 2 shows characteristics of the analytic sample. Based on the IOM 2009 weight gain guidelines, a majority of women (56%) showed excessive GWG, 27% adequate GWG, and 16% inadequate GWG. In the first trimester, 37 women lost weight (3.4±2.2 kg) and 5 women had no weight gain (0 kg Δ); for total GWG, 2 women (1.3%) lost weight during pregnancy (0.5 and 5 kg). Few women gained within the 2009 IOM rate guidelines for the second (n=23, 15%) or third (n=18, 12%) trimesters. Overall, gain (and rate of gain) was 1.9±3.9 kg (rate: 0.15±0.3 kg/wk) in the first trimester, 7.4±3.0 kg (rate: 0.49±0.2 kg/wk) in the second trimester, and 6.4±3.4 kg (rate: 0.52±0.3 kg/wk), in the third trimester. In unadjusted analyses, total and rate of GWG varied by parity; specifically, parous mothers had significantly lower rates of GWG in the second and third trimester [GWG: 2nd: 0.44±0.21 vs. 0.54±0.18 kg/wk, p<0.001; 3rd trimester: 0.44±0.27 vs. 0.60±0.23 kg/wk, p<0.001] than nulliparous women. For race/ethnicity, we only evaluated differences among Hispanic/Non-Hispanic Whites and Blacks, as there were too few women (n=3) in the other category; GWG rate differed by race/ethnicity in the first (p=0.002) and second trimester (p=0.02), but not the third trimester. In the first trimester, mean rate of GWG was 0.23±0.31 kg/wk for Non-Hispanic Black, 0.03 ± 0.35 kg/wk for Hispanic Black, 0.11±0.28 kg/wk for White Hispanic, and 0.19 ± 0.17 kg/wk for Non-Hispanic White. In the second trimester, mean rate of GWG was 0.43±0.23 kg/wk for Non-Hispanic Black, 0.50 ± 0.19 kg/wk for Hispanic Black, 0.51±0.20 kg/wk for White Hispanic and 0.52±0.13 kg/wk for Non-Hispanic White. Trimester GWG did not vary by infant sex.

Table 3 shows total GWG and rate of GWG by tertile and trimester. Total GWG in the first trimester was not correlated with second or third trimester GWG (1st & 2st trimester GWG: r = 0.12, p=0.1; 1st & 3rd trimester GWG: r = 0.−0.08, p=0.3); however, total GWG in the second trimester was positively correlated with third trimester GWG (r = 0.42, p<0.001). Similarly, rate of GWG in the first trimester was not correlated with rate of GWG in the second or third trimester (1st & 2nd trimester rate GWG: r = 0.12, p=0.1; 1st & 3rd trimester rate GWG: r = −0.09, p=0.3); while rate of GWG in the second trimester was positively associated with third trimester rate of GWG (r = 0.39, p<0.001).

The pattern and rate of GWG was associated with maternal body composition changes (Table 4). Compared with the lowest GWG group, women who gained in the medium and high GWG groups gained more fat from 14 to 37 weeks gestation, controlling for prepregnancy BMI, fat mass at 14 weeks, and weight gain in the other trimesters. Although medium *total* GWG was associated with greater fat mass gain in the third trimester, medium *rate* of GWG was not.

The pattern of total GWG in the second and third trimesters was also associated with body water changes. Controlling for prepregnancy BMI, body water at 14 weeks and weight gain in the other trimesters, compared with the lowest group, the medium total GWG group in the second trimester and the high GWG groups (total and rate) in the third trimester were associated with larger increases in body water.

In another set of linear regression models, the association between IOM rates of GWG and maternal body composition changes were evaluated. Compared with those who gained within the IOM rate guidelines, gaining above the IOM rate guidelines in the second and third trimester was associated with greater gains in fat mass from 14 to 37 wk (2nd Trimester β=3.33 kg, p<0.001; 3rd trimester β=2.6 kg, p=0.008). Gaining below the guidelines was not associated with fat mass changes. Adherence to the IOM rate guidelines was not associated with body water changes.

The trimester-specific pattern of GWG was associated with newborn weight and length (Table 5). A significant effect of high pregnancy weight gain in the second trimester was observed in women with prepregnancy BMI values <24 kg/m^2, compared with the low gain group, and effects were greater in thinner women. Predicted infant birth weight was increased by 823 g (p=0.01), 755 g (p=0.02), and 687 g (p=0.03) for women with a prepregnancy BMI of 18, 20 and 23 kg/m^2, respectively; these estimates are based on linear combinations of the beta coefficients for n BMI (e.g., prepregnancy BMI β *n + Trimester 2 High β + Trimester 2 High β*Prepregnancy BMI β*n). For women with higher prepregnancy BMI (≥24 kg/m^2), the pattern of weight gain was not associated with infant birth weight (all p>0.05). High rate of GWG in the second trimester was associated with higher birth weight, but effects did not differ by prepregnancy BMI. For birth length, GWG in the first trimester was not associated with birth length. In the second trimester, high total and rate of GWG were associated with longer birth length. In the third trimester, no significant associations between pattern of GWG and infant weight or length were observed.

Discussion

These data suggest that the pattern and rate of GWG are associated with changes in maternal body composition and infant birth weight and length. GWG in the second and third trimesters is associated with both fat mass and body water changes in the mother, while GWG in the second trimester is associated with newborn size.

No prior studies have evaluated how the pattern of GWG relates to changes in maternal body composition. Previously, data from this cohort had shown that greater total GWG was positively associated with gains in body fat (*r* =0.81, p<0.001), but not with increases in body water (Lederman et al., 1997). In another cohort of 63 women (24% overweight/ obese), total GWG was positively associated with gains in both TBW (*r* = 0.39, p=0.003) and fat mass (*r* =0.76, p=0.001) (Butte et al., 2003). Fat mass gain varied by BMI group, where women with high BMI (≥ 26 kg/m^2) gained greater fat mass and weight, compared to normal weight women (FM: 8.4±4.1 kg vs. 4.6±4.0 kg, p=0.03; body weight: 16.6±5.4 kg vs. 12.8±4.4 kg, p=0.04) (Butte et al., 2003). In our cohort, obese women gained less weight and fat than lower weight women (Lederman et al., 1997); this difference between studies may be attributable to small sample size in the overweight/obese group in the Butte et al. report (n=12, BMI (mean±SD) 28.8 ± 2.6 kg/m^2) (Butte et al., 2003).

In this report, we extend these findings to include the trimester specific pattern of GWG. We observed that greater total weight gains in the second and third trimesters are associated with larger gains in fat mass. The rate of GWG was also associated with gain in fat mass. In the second trimester, higher rates of GWG (medium and high groups) were associated with greater total gains in fat mass; in the third trimester, the highest GWG rate is associated greater fat mass gain. We also show that exceeding the IOM recommended rates of weight gain was associated with greater increases in fat mass, compared to those who gained within the guidelines. For body water, women in the medium group of total weight gain in the second trimester had larger total body water increases, compared to women with low total GWG. In the third trimester, women with high total GWG and rate of GWG had greater changes in TBW, compared to the corresponding low gain groups. Together, these findings indicate that GWG in both the second and third trimesters are important determinants of maternal fat mass and body water gains. The strongest effects of GWG on body fat were seen for gain in the second trimester, thus this period may be important for interventions to prevent excessive fat gain.

Our observations that high GWG in the second trimester was associated with birth weight and length are in agreement with other reports (Abrams & Selvin, 1995; Brown et al., 2002; Hickey, Cliver, McNeal, Hoffman, & Goldenberg, 1996; Margerison-Zilko et al., 2012). In 2,994 predominately normal-weight women, total GWG in each trimester was positively associated with higher infant birth weight, and further, some patterns with low GWG were associated with lower birth weight (Abrams & Selvin, 1995). Regardless of the pattern of GWG in the first and third trimester, birth weight effects were strongest among those with low GWG in the second trimester (Abrams & Selvin, 1995). Similar associations were observed in a cohort of 414 non-obese black and white women, where low gain in the second trimester was associated with lower birth weight (Hickey et al., 1996). In contrast to these findings, Brown et al. (Brown et al., 2002) observed that total GWG in the first trimester was the strongest predictor of infant birth weight or length. In contrast, we did not observe an association between first trimester GWG and infant size. These differences could possibly be due to differences in how prepregnancy weight was obtained between samples (self-report vs. measured), neonatal measurement protocols, or differences in population characteristics. For example, the majority of the participants in Brown et al. (Brown et al., 2002) were white with a normal BMI, while our sample was multi-ethnic and ~36% overweight/obese.

We also observed that effects of high total GWG in the second trimester on infant birth weight differed by prepregnancy BMI. Among women with lower prepregnancy BMI (<24 kg/m^2), high weight gain in the second trimester was associated with higher infant birth weight with larger effects in thinner women, while high second trimester weight gain among heavier women (prepregnancy BMI≥24) was not associated with heavier infant birth weight.

Effect modification by prepregnancy BMI has previously been observed in the first trimester in a cohort of 3,015 predominately normal weight white women and their infants (births from 1959–1967), where the estimated birth weight (adjusted for gestational age) for every 1 kg increase in GWG was lower for women with higher prepregnancy BMI values (Margerison-Zilko et al., 2012). Whereas, we observed that positive associations between high 2^{nd} trimester GWG and infant birth weight among women who had lower prepregnancy BMI values (<24 kg/m^2), but not among heavier women. This difference may be attributable to sample differences between cohorts. In our sample overweight/obesity prevalence and total trimester GWG were higher, but our sample size was smaller, limiting our ability to detect significant interactions. Several other studies have characterized the adequacy of early and late pregnancy weight gain in relation to offspring size (Hediger, Scholl, Belsky, Ances, & Salmon, 1989; Neufeld, Pelletier, & Haas, 1999). The association between trajectory patterns of GWG and infant size/fetal growth has also been previously reported (14). Due to differences in the timing of GWG (early vs. late) or use of the GWG trajectory pattern across pregnancy, it is challenging to compare these reports to our findings.

Our study has limitations. First, compared to women not included in this analysis, included women gained more weight and body water. Maternal fat mass changes and infant anthropometry at birth did not differ between those included and excluded from the analytic sample. Thus, there is some evidence of selection bias for those who were enrolled in this analytic cohort. This type of selection bias, however, is irremediable without additional information about what factors were associated with inclusion (e.g., what factors determined whether women would have prenatal weight records available). That would allow for use of methods such as inverse-probability weighting for quantifying the effect of this bias on observed associations.

While we were able to evaluate associations between outcomes and the trimester-specific pattern of total and rate of GWG, we were unable to evaluate whether shifts between groups (e.g., low gain in first trimester to high gain in second and third trimesters) were associated with maternal and infant outcomes, as this would require a substantially larger sample. Furthermore, we may have been underpowered to detect significant interactions between the pattern of GWG and prepregnancy BMI. Since weight measurements were obtained at various gestational ages, we interpolated trimester specific weight measurements by assuming linearity between measured weights; an approach previously used by Abrams and colleagues (Abrams & Selvin, 1995). We used the interpolation approach to allow for simple interpretation by prenatal care providers and for comparisons across studies that have previously described trimester-specific GWG. Our gold-standard estimate of body fat changes in pregnancy assumed minimal changes in total body bone mineral between the two pregnancy body composition measurements (at about 14 and 37 weeks) (Widen & Gallagher, 2014). Some studies report no changes (Christiansen, Rodbro, & Heinild, 1976; Naylor, Iqbal, Fledelius, Fraser, & Eastell, 2000; Prentice, 1994; Ritchie et al., 1998; Sowers, Crutchfield, Jannausch, Updike, & Corton, 1991) and others report small changes (Black, Topping, Durham, Farquharson, & Fraser, 2000; Drinkwater & Chesnut, 1991; Lamke, Brundin, & Moberg, 1977; Olausson, Laskey, Goldberg, & Prentice, 2008) in total body bone or site-specific bone over the whole course of pregnancy. We concluded that estimates of bone improved the estimates of body fat and water sufficiently to warrant inclusion of a bone measurement, despite potential small changes.

We were also unable to evaluate how the pattern of GWG in the first trimester related to changes in maternal body composition, as body composition was measured after this period. Although women with known medical conditions requiring medication, such as diabetes, were excluded, gestational diabetes was not assessed in this study. Because risk of gestational diabetes is lower in normal weight women and nonsmokers (Zhang et al., 2014), we expect the prevalence of gestational diabetes to be low in our sample of non-smoking, predominately normal weight, women. Finally, the race/ethnicity composition of our analytic sample—Non-Hispanic Black, Non-Hispanic White, Hispanic Black, Hispanic White, and Non-Hispanic Other—may limit its external validity.

Although data were collected approximately 20 years ago, no studies, to our knowledge, have examined these associations in a single cohort. It is important to note that, when this study was conducted, the IOM GWG guidelines (Institute of Medicine, 1990) used different BMI categories and were less stringent for obese women. At least 15 lbs weight gain was recommended for women with prepregnancy BMIs above 29 kg/m^2 (Institute of Medicine, 1990); the current guidelines revised the BMI categories and recommended 11–20 lbs gain for obese women (Institute of Medicine, 2009).

Prevalence of overweight and obesity among women of childbearing age has also increased since these data were collected, going from approximately 42% (Institute of Medicine, 2009) (1988–1994) to 59% (Ogden, Carroll, Kit, & Flegal, 2014). Further, prevalence of Class II and Class III obesity (BMI≥35 kg/m^2) has also increased from 9.4% to 15.4% (Institute of Medicine, 2009; Ogden et al., 2014). In our sample, 36% of women were overweight or obese, and few women (5%) had Class II or Class III obesity. In addition, GWG trends have also shifted with a larger proportion of women gaining above 40 lbs or below 16 lbs, while women gaining within 16–40 lbs slowly declined from 1990–2005 (Institute of Medicine, 2009). Unfortunately, trends in the pattern of weight gain during this period are not available. While it is possible that our analytic sample may not be fully generalizable to women today, these questions still merit investigation to guide GWG recommendations and interventions, and to provide insight for future studies in this area. Future research evaluating the how maternal weight gain patterns relate to neonatal adiposity and postpartum weight retention is recommended.

We have shown that the pattern and rate of GWG are associated with changes in maternal body composition in pregnancy and to infant size at birth. The pattern of GWG in both the second and third trimesters is an important predictor of maternal body composition changes. For fat mass, medium and high rate of GWG in the second trimester and high rate of GWG in the third trimester are associated with an estimated ~3–5 kg of fat mass gain. For infant outcomes, high GWG in the second trimester is associated with almost a centimeter greater birth length. Furthermore, high rate of GWG is associated with approximately 350 grams greater birth weight. These are clinically relevant values and have important implications for later infant size, as linear growth and weight track across the life course, and for maternal size as well, as fat mass gains have previously been associated with greater postpartum fat retention (Butte et al., 2003). Together, these indicate that monitoring the pattern of GWG may be beneficial for supporting healthy GWG, which ultimately will promote both maternal and child health.

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Abbreviations

BMI	body mass index
DP	whole-body ^{153}Gd dual-photon absorptiometry
DXA	dual energy absorptiometry
GWG	gestational weight gain
IOM	Institute of Medicine
TBW	total body water

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Table 1

Gestational weight gain coding by trimester

	Trimester 1	Trimester 2	Trimester 3
Total GWG[1], kg			
Low	≤0	≤5.6	≤4.1
Medium	0.1–4.0	5.7–8.9	4.2–8.1
High	≥4.1	≥9.1	≥8.2

[1]Group allocation for total GWG was defined <25%ile for low GWG and ≥75%ile for high GWG.

GWG, gestational weight gain

Table 2

Sample characteristics

	n=156
Maternal	
Age, years	26.4 ± 4.7
Prepregnancy weight, kg	63.6 ± 13.6
Height, cm	161.3 ± 7.1
Prepregnancy BMI, kg/m^2	24.5 ± 4.9
Prepregnancy BMI Categories, n (%)	
Underweight (<18.5 kg/m^2)	6 (3.9)
Normal weight (18.5–24.9 kg/m^2)	94 (60.3)
Overweight (25.0–29.9 kg/m^2)	37 (23.7)
Obese (> 30 kg/m^2)	19 (12.2)
Total GWG, kg	15.6 ± 6.6
Fat mass change from 14–37 wk, kg	3.3 ± 4.5
TBW change from 14–37 wk, L	7.3 ± 3.0
Maternal race-ethnicity[1], n (%)	
Non-Hispanic White	33 (21.2)
White Hispanic	46 (29.5)
Non-Hispanic Black	40 (25.6)
Black Hispanic	34 (21.8)
Other Non-Hispanic	3 (1.9)
Primiparous, n (%)	82 (52.6)
Infant	
Sex, n (%)	
Male	89 (57.1)
Female	67 (43.0)
Birth length[2], cm	20.3 ± 1.2
Birth weight, g	3458.0 ± 449.3
Gestational age at delivery, wk	40.3 ± 1.8

[1] Other race includes one American Indian and two self-reported “other race” [unspecified]

[2] Birth length was available on 137 infants

Mean ± SD, all such values.

Table 3

Gestational weight gain by group and trimester (n=156)

	Trimester 1	Trimester 2	Trimester 3
Total GWG[1], kg			
Low	−3.00 ± 2.38 (42)	3.70 ± 1.62 (39)	2.75 ± 1.30 (43)
Medium	2.22 ± 1.06 (74)	7.36 ± 0.98 (77)	6.25 ± 1.04 (73)
High	6.47 ± 1.92 (40)	11.01 ± 2.04 (40)	10.79 ± 2.70 (40)
Weekly trimester GWG[2], kg/wk			
Low	−0.16 ± 0.20 (56)	0.29 ± 0.12 (54)	0.26 ± 0.11 (51)
Medium	0.18 ± 0.05 (47)	0.50 ± 0.05 (50)	0.51 ± 0.06 (51)
High	0.44 ± 0.16 (53)	0.70 ± 0.14 (52)	0.79 ± 0.21 (54)

[1]For the first, second and third trimesters, low GWG in was defined as gain of ≤25%ile and high GWG was ≥75%ile.

[2]Grouped into tertiles

Mean ± SD (n). GWG, gestational weight gain

Table 4

Linear regression models of change in maternal body composition from 14 to 37 weeks gestation by trimester GWG[1]

	Fat Δ, kg n=152			TBW Δ, L n=156		
	Coef.	95% Confidence Interval	p-value	Coef.	95% Confidence Interval	p-value
Weight gain, kg						
Initial value[2]	−0.09	(−0.20, 0.03)	0.14	−0.20	(−0.32, −0.08)	0.002
Prepregnancy BMI	−0.06	(−0.29, 0.17)	0.63	0.23	(0.11, 0.35)	<0.001
Trimester 2 Medium	2.72	(1.36, 4.08)	<0.001	1.37	(0.19, 2.54)	0.02
Trimester 2 High	5.56	(3.95, 717)	<0.001	1.23	(−0.18, 2.64)	0.09
Trimester 3 Medium	1.97	(0.66, 3.29)	0.003	0.78	(−0.35, 1.91)	0.17
Trimester 3 High	4.55	(2.76, 6.34)	<0.001	1.85	(0.30, 3.40)	0.02
Rate of weight gain, kg/wk						
Initial value[2]	−0.05	(−0.16, 0.06)	0.37	−0.21	(−0.33, −0.08)	0.001
Prepregnancy BMI	−0.12	(−0.34, 0.10)	0.30	0.22	(0.10, 0.34)	<0.001
Trimester 2 Medium	2.86	(1.56, 4.17)	<0.001	0.79	(−0.40, 1.99)	0.19
Trimester 2 High	5.29	(3.99, 6.58)	<0.001	0.56	(−0.66, 1.77)	0.37
Trimester 3 Medium	1.00	(−0.22, 2.23)	0.11	0.68	(−0.45, 1.80)	0.24
Trimester 3 High	3.63	(2.27, 5.00)	<0.001	1.75	(0.49, 3.02)	0.01

[1] Low tertile is reference for each trimester.

[2] Initial value refers to initial body fat (kg) or TBW (L) measure. Models adjusted for gestational age at delivery, maternal education, race/ethnicity, age, parity and infant sex.

BMI, body mass index; GWG, gestational weight gain; TBW, total body water.

Table 5

Linear regression models of newborn weight and length by GWG pattern by trimester[1]

	Birth weight, g n=156			Birth length, cm n=137		
	Coef.	95% Confidence Interval	p-value	Coef.	95% Confidence Interval	p-value
Weight gain[2], kg						
Prepregnancy BMI	8.5	(−16.4, 33.4)	0.50	0.03	(−0.02, 0.07)	0.21
Trimester 1 Medium	−291.2	(−1235.8, 653.4)	0.54	0.42	(−0.08, 0.92)	0.10
Trimester 1 High	−615.6	(−16.07.1, 375.9)	0.22	0.49	(−0.05, 1.02)	0.08
Trimester 2 Medium	461.4	(−370.9, 1293.7)	0.28	0.27	(−0.22, 0.77)	0.27
Trimester 2 High	1437.1	(267.9, 2606.4)	0.02	0.82	(0.21, 1.43)	0.01
Trimester 3 Medium	242.6	(−573.4, 1058.5)	0.56	−0.16	(−0.63, 0.31)	0.50
Trimester 3 High	−383.2	(−1536.7, 770.3)	0.51	0.08	(−0.57, 0.73)	0.81
Trimester 1 Medium*Prepregnancy BMI	15.4	(−22.6, 53.4)	0.43		-	
Trimester 1 High*Prepregnancy BMI	28.7	(−9.7, 67.1)	0.14		-	
Trimester 2 Medium*Prepregnancy BMI	−15.3	(−48.1, 17.5)	0.36		-	
Trimester 2 High*Prepregnancy BMI	−42.6	(−89.3, 4.0)	0.07		-	
Trimester 3 Medium*Prepregnancy BMI	−12.2	(−44.9, 20.5)	0.46		-	
Trimester 3 High*Prepregnancy BMI	10.0	(−36.1, 56.0)	0.67		-	
Rate of weight gain, kg/wk						
Prepregnancy BMI	−0.5	(−14.5, 13.5)	0.94	0.02	(−0.02, 0.06)	0.29
Trimester 1 Medium	−84.8	(−248.0, 78.3)	0.31	−0.12	(−0.60, 0.36)	0.63
Trimester 1 High	33.8	(−130.7, 198.2)	0.69	0.22	(−0.26, 0.69)	0.37
Trimester 2 Medium	29.1	(−138.6, 196.8)	0.73	0.39	(−0.10, 0.89)	0.12
Trimester 2 High	355.9	(182.1, 529.7)	<0.001	0.85	(0.33, 1.38)	0.002
Trimester 3 Medium	−113.6	(−270.4, 43.2)	0.15	−0.17	(−0.63, 0.29)	0.47
Trimester 3 High	−83.6	(−259.1, 91.8)	0.35	−0.23	(−0.74, 0.29)	0.38

[1] Low tertile of gestational weight gain is reference for each trimester. Adjusted for gestational age at delivery, maternal education, race/ethnicity, age, parity and infant sex.

[2] An interaction term between prepregnancy BMI and total weight gain pattern is included in the model with infant birth weight outcomes; thus, individual effect estimates cannot be interpreted without accounting for prepregnancy BMI. For illustration, predicted infant birth weight was increased by 823 g (p=0.01), 755 g (p=0.02), and 687 g (p=0.03) for women with a prepregnancy BMI of 18, 20 and 23

kg/m2, respectively; these estimates are based on linear combinations of the beta coefficients for n BMI (e.g., prepregnancy BMI β *n + Trimester 2 High β + Trimester 2 High β*Prepregnancy BMI β*n). For women with higher prepregnancy BMI (≥24 kg/m2), the pattern of weight gain was not associated with infant birth weight (all $p>0.05$).

BMI, body mass index; GWG, gestational weight gain; TBW, total body water.