Published in final edited form as:

Am J Obstet Gynecol. 2016 June ; 214(6): 745.e1–745.e5. doi:10.1016/j.ajog.2015.12.026.

Maternal fat, but not lean, mass is increased among overweight/obese women with excess gestational weight gain

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Abstract

Background—Weight gain in pregnancy is an essential physiological adaptation, supporting growth and development of a fetus, and is distributed among lean mass including total body water, and fat mass gains. Although gestational weight gain provides a source of energy for the mother and fetus, excess gestational weight gain may underlie reported associations between parity and future metabolic disorders, and is linked to postpartum weight retention and insulin resistance. Although weight gain is often proposed as a modifiable variable to mitigate adverse maternal and offspring health outcomes, our knowledge of specific maternal body composition changes with weight gain, and the potential metabolic consequences, is limited. Furthermore, although gestational weight gain alters maternal body composition, the impact of excess weight gain on fat and lean mass is not well studied. Understanding the accrual of fat and lean body mass may improve our understanding of the role of excessive gestational weight gain and metabolic dysfunction.

Objective—To quantify the relationship between gestational weight gain and maternal fat and lean body mass accrual, and to compare fat and lean body mass accrual according to 2009 Institute of Medicine Guidelines for Gestational Weight Gain in Pregnancy adherence. We hypothesized that exceeding current weight gain guidelines would be associated with greater fat, compared with lean body, mass accrual.

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Conflict of Interest: None of the authors report any conflict of interest.

This research was presented in poster format at the 75th Scientific Sessions of the American Diabetes Association, Boston, MA, June 5-9, 2015

Condensation: Excess gestational weight gain in overweight/obese women is associated with proportionally greater accrual of fat, but not lean, mass

Study Design—This is a secondary analysis of a randomized controlled trial of 49 overweight/obese women; all 49 are included in this secondary analysis. Maternal weight and body composition using air densitometry (BOD POD) were collected in early (13 0/6–16 6/7 weeks) and late (34 0/7–36 6/7 weeks) pregnancy. Correlations were made between gestational weight gain and change in fat and lean body mass. We compared change in fat and lean body mass by adherence to 2009 Institute of Medicine Guidelines for Gestational Weight Gain in Pregnancy. Nonparametric tests and Chi-Square analyses were performed, reporting median [interquartile range, IQR] and n (%), respectively, with $p < 0.05$ significant.

Results—Early pregnancy body mass index was 30.3 [28.5–35.2] kg/m²; women gained 9.0 [5.3–13.2] kg. Overweight and obese women were equally likely to gain excess weight (48% vs. 35%, $p = 0.6$). Weight gain correlated strongly with fat mass change ($r = 0.87$, $p < 0.001$); women with excess vs. adequate vs. inadequate weight gain had greater fat mass change, overall (5.2 [4.2–8.1] vs. 0.2 [–0.4–2.2] vs. –2.7 [–5.2––0.7] kg, $p < 0.001$) and in all pairwise comparisons. Weight gain also correlated with lean body mass change ($r = 0.52$, $p = 0.001$), but women with excess vs. adequate weight gain had similar lean body mass change (8.4 [7.2–10.1] vs. 7.8 [6.0–8.7] kg, $p = 0.1$).

Conclusion—Excess gestational weight gain is associated primarily with maternal fat, but not lean body mass accrual. Our results may help explain why excess gestational weight gain, or fat mass accrual, is associated with long-term obesity, metabolic dysfunction, and cardiovascular disease risk.

Keywords

gestational weight gain; maternal body composition; maternal fat mass; maternal lean body mass

Introduction

Weight gain in pregnancy is an essential physiological adaptation, supporting growth and development of a fetus, and is distributed among lean mass including total body water, lean mass, and fat mass gains.¹ Approximately 35% of gestational weight gain (GWG) is products of conception, including the fetus, placenta, and amniotic fluid.² The remaining GWG is maternal. Lean body mass accrual occurs throughout pregnancy and is primarily water; only up to ~1 kilogram of lean mass is protein and is accrued primarily in late pregnancy.^{3–6} Fat mass is accrued up to about 30 weeks' gestation and may continue until delivery.^{7,8} Using the 1990 Institute of Medicine (IOM) Guidelines for Weight Gain in Pregnancy, fat mass accrual among women gaining within or above guidelines was greatest among underweight women, followed by normal weight, and overweight, with obese women gaining the least fat mass in one study,^{9, 10} but this trend is not consistently reported^{6, 11} and has not been described using the current IOM GWG guidelines.

Although GWG provides a source of energy for the mother and fetus,¹ excess GWG may underlie reported associations between parity and future risk of obesity and other metabolic disorders.¹² Excess GWG is associated with postpartum weight retention and insulin resistance,^{12, 13} and is routinely targeted as a modifiable outcome, aiming to mitigate the associated short- and long-term adverse perinatal outcomes. Different contributions of fat

and lean mass accrual in GWG have not been considered in light of the current IOM GWG guidelines but should be a priority, as more than half of overweight/obese women exceed 2009 IOM GWG guidelines.^{13, 14} Thus, specifically delineating the accrual of fat mass may improve our understanding of the role of excessive GWG and metabolic dysfunction. We measured the change in fat and lean body mass in a prospective pregnant cohort and hypothesized that exceeding current weight gain guidelines would be associated with greater fat, compared with lean body mass.

Materials and Methods

We conducted a secondary analysis of overweight/obese women enrolled in a randomized controlled trial conducted at a single university hospital from September 2009 – August 2011 and designed to measure whether omega-3 (fish oil) supplements reduced inflammation in a pregnant population.¹⁵ The primary study measures were performed during two outpatient visits in the Clinical Research Unit (CRU) at MetroHealth Medical Center/Case Western Reserve University. Visits 1 and 2 occurred in early (13 0/7 – 16 6/7 weeks) and late (34 0/7 – 36 6/7 weeks) pregnancy, respectively. MetroHealth Medical Center/Case Western Reserve University Institutional Review Board approval is maintained for this study, and written informed consent was obtained for each woman prior to performing any study procedures.

Women were recruited for the original trial if they met inclusion criteria: singleton pregnancy from gestational age 8 0/7 – 16 6/7 weeks (determined by last menstrual period and confirmed or changed by ultrasound prior to 20 0/7 weeks per standard clinical parameters) and planned to deliver at the clinical site. Women were excluded from the original trial if they had known fetal anomaly, used a non-steroidal anti-inflammatory agent daily, had a pre-existing metabolic disorder (hypertension, diabetes, hyperthyroidism), were HIV positive, used tobacco in pregnancy, illicit drug or alcohol use, or had a fish allergy or gluten intolerance (RCT placebo contained wheat germ oil).

All women who completed primary study procedures remained eligible for the current analysis, and procedures specific to the current analysis are described as follows. At Visit 1, maternal demographic, medical, and pregnancy history data were prospectively collected. Maternal height without shoes was measured with a stadiometer to the nearest 1.0 mm and weight with a tared hospital gown was measured with a calibrated scale (Toledo, Inc. Toledo, OH) to the nearest 0.01 kg. Body mass index (BMI) was calculated as kg/m^2 . Body composition was estimated using air densitometry (BOD POD, COSMED USA, Inc. Concord, CA), reporting total lean and fat mass to the nearest 0.01 kg. Calculations of percent body fat were specific to early pregnancy^{16, 17} and late gestation¹⁸ time points, using previously developed formulas that use a hydration constant to account for the increased contribution of water to lean body mass in late pregnancy.

Our primary exposure was gestational weight gain (GWG), calculated by subtracting weight at Visit 1 from Visit 2. We classified women as overweight (BMI 25.0 – 29.9 kg/m^2) and obese (BMI > 30 kg/m^2) based on Visit 1 BMI and as having adequate versus excess GWG according to the 2009 Institute of Medicine Guidelines for Gestational Weight Gain in

Pregnancy.¹³ Outcome variables included the change in maternal lean body mass (LBM) and fat mass (FM), also calculated by subtracting Visit 1 from Visit 2 measures.

We described the cohort using nonparametric tests and Chi-Square for continuous and categorical variables, respectively, reporting median with interquartile range [IQR] or total n (%). We measured Spearman's correlations between GWG and FM and between GWG and LBM for the full cohort, and separately for overweight and obese women, reporting r . We compared FM and LBM by adherence to 2009 IOM GWG guidelines (inadequate vs. adequate vs. excess GWG) using Kruskal-Wallis test, then pairwise comparisons for significant overall findings. Multivariable regression evaluated the impact of potential maternal characteristics and randomization to omega-3 supplementation on results. Randomization to receive omega-3 supplementation was not a significant covariate in the relationship between GWG and either FM or LBM (data not shown); thus, all results are reported as one cohort. $P < 0.05$ was considered significant for all analyses.

Results

A total of 49 women completed all study procedures and were eligible for this analysis. Descriptive characteristics are shown in Table 1. Overweight and obese women were equally likely to adhere to GWG guidelines, as shown in Table 2. Maternal fat and lean body mass were similar in early pregnancy for overweight and obese women, regardless of subsequent adherence to GWG guidelines, as shown in Table 3.

Median FM was 1.2 [−1.1–4.6] kg. GWG was strongly positively correlated with FM in the full cohort ($r=0.87$, $p<0.001$), and among overweight ($r=0.72$, $p<0.001$) and obese ($r=0.93$, $p<0.001$) women (Figure 1A). Median FM was greatest among women with excess vs. adequate vs. inadequate GWG (5.2 [4.2–8.1] vs. 0.2 [−0.4–2.2] vs. −2.7 [−5.2–0.7], $p<0.001$) and all pairwise comparisons remained significant (Figure 1B).

Median LBM was 7.4 [6.2–9.3] kg. GWG was positively correlated with LBM in the full cohort ($r=0.52$, $p=0.001$), and among overweight ($r=0.63$, $p=0.01$) and obese ($r=0.47$, $p=0.02$) women (Figure 2A). Median LBM differed among women with excess vs. adequate vs. inadequate GWG (8.4 [7.2–10.1] vs. 7.8 [6.0–8.7] vs. 6.8 [5.3–7.5], $p=0.03$). In pairwise comparisons, however, women with inadequate vs. adequate, and adequate vs. excess GWG had similar LBM. Only women with inadequate, compared with excess, GWG had lower LBM ($p=0.01$) (Figure 2B).

To evaluate the potential impact of covariates on our results, multiple regression analyses were performed. Visit 1 BMI was a significant covariate in the relationship between GWG and FM ($p=0.04$), and LBM ($p=0.03$), but it did not alter the magnitude and significance of the unadjusted relationships. No other collected maternal characteristics were significant covariates in these relationships.

Comment

We report a significant correlation between gestational weight gain and accrual of maternal fat mass. Excess, compared with adequate, GWG was associated with significantly greater

fat mass accrual. Inadequate, compared with adequate, GWG was associated with significantly less fat mass accrual. The absolute difference in median fat mass accrual between inadequate and excess GWG was 7.9 kg. Although there was also a positive correlation between GWG and lean body mass accrual, only inadequate, compared with excess, GWG was associated with significantly different lean body mass accrual with an absolute difference of 1.6 kg. The proportion of fat and lean body mass accrual varied by IOM adherence, where women with excess GWG gain 60% lean mass and 40% fat mass, women with adequate GWG gain 96% lean mass and only 4% fat mass, and women with inadequate GWG only gain lean mass while losing fat mass.

Our findings are consistent with others who used robust techniques for body composition measurement in pregnancy. Lederman, et al.¹⁰ and Butte, et al.⁶ reported positive linear correlations between GWG and FM accrual of $r=0.81$ and $r=0.76$, respectively, mirroring our similarly strong positive correlation. However, not all findings agree. Lederman, et al. also reported an inverse relationship between GWG and early pregnancy BMI,¹⁰ while Butte, et al. found a positive relationship.⁶ In our cohort, fat mass accrual is also positively correlated with early pregnancy BMI. We speculate this may be explained by our cohort's similar body composition at Visit 1 and that women in each BMI class were equally likely to adhere to current IOM GWG guidelines. Inconsistent findings may also reflect differences in degree of obesity, as our cohort was comprised of overweight and obese women, compared with the lower mean BMI, including underweight and normal weight women in Lederman, et al.¹⁰

The small but significantly lower LBM accrual with inadequate, compared with excess, GWG also warrants mention. This parallels findings from Catalano, et al.¹⁹ in a analysis of Maternal-Fetal Medicine Units Network data, that demonstrated weight loss or inadequate weight gain among overweight/obese women is linked to small-for-gestational age neonates with decreased fat and lean mass, compared with neonates of women who had adequate weight gain. The current analysis, with a seemingly small absolute difference in maternal LBM accrual, may still represent a clinically meaningful difference. This 1.6 kg difference may partially explain the link to SGA neonates, though other etiologies of SGA neonates unrelated to GWG, such as placental sufficiency, cannot be disregarded as possible contributors. Nonetheless, it seems appropriate at this juncture to avoid recommendations for weight loss among overweight/obese women, as the proportion of lean body mass to total GWG shifts considerably according to IOM Guidelines adherence.

Our reported associations apply the current 2009 IOM Guidelines for Weight Gain in Pregnancy and highlight the limitations of using only BMI and GWG in research on maternal and offspring outcomes. Neither fat mass nor fat mass accrual are adequately estimated using only BMI and GWG. Preconception and early pregnancy BMI correlate with fat mass, but this correlations lessens in later pregnancy as total body water contributes a greater proportion of GWG.²⁰ Thus, although several recent publications link excess gestational weight gain to adverse maternal or neonatal outcomes, a more appropriate interpretation may be that the adverse metabolic consequences are related to excess maternal fat mass accrual.

Adiposity, impacted by further fat accumulation, is a pro-inflammatory state. In pregnancy, the two-fold increased risk of pre-eclampsia among obese women²¹ may be partially explained by the pro-inflammatory state of an obese woman, with elevated circulating inflammatory mediators and cytokine concentrations.²² We acknowledge that pre-pregnancy adiposity, and not GWG or pregnancy-related fat mass accrual, is a stronger predictor of adverse pregnancy outcomes. Pregnancy is a unique time, where weight gain is physiologic and expected. However, excess fat mass accumulation that accompanies excess GWG may exacerbate pregnancy complications and long-term metabolic consequences. Moreover, perhaps it is the excess fat mass accrual that explains postpartum weight – and fat – retention, thus increasing adiposity before a subsequent pregnancy and perpetuating the cycle and long-term metabolic consequences. Finally, the fat mass accrual that contributes to excess GWG may drive fetal adiposity and contribute to the transgenerational risk of obesity.

Strengths of this study include its original prospective design and robust methodology. As part of a recent randomized controlled trial,¹⁵ women were closely followed through pregnancy. Thus, we approximate an observational study, measuring the natural course of GWG after implementation of the current 2009 GWG Guidelines for Weight Gain in Pregnancy.¹³ Our estimates of maternal body composition in early and late pregnancy are specific to gestational age and use a hydration constant that accounts for physiologic changes in pregnancy and total body water content of lean tissue.

Our study also has limitations. Our data may not be applicable to women outside of the overweight/obese BMI class. As ours is a secondary analysis, we are constrained by BMI criteria of the original trial. A parallel analysis among underweight or normal weight women may or may not demonstrate similar relationships. By using early and late pregnancy weight, it is possible we over- or underestimated total GWG that occurred outside this window, and thus, misclassified IOM adherence. Although misclassification may be possible, using early and late pregnancy measured weight does not likely alter magnitude or significance of linear correlations that were not dependent on IOM GWG adherence, or that excess GWG within our gestational age limits appears to be attributed to fat mass.

In conclusion, although it would appear intuitive, we have now demonstrated that excess GWG in overweight/obese pregnant women is primarily associated with excess fat and not lean mass accrual. Relying on total GWG, without considering pregnancy-related alterations in body composition, limits our understanding of reported associations between GWG and adverse pregnancy outcomes. It may also underlie the inconsistent or negative findings of current intervention studies. Although it may not be feasible to incorporate the specific methodologies used in the current analysis, a clear understanding of maternal metabolism, body composition changes, and clinical consequences should play an integral role in future research.

Acknowledgements

We thank the Clinical Research Unit (CRU) research nurses for their work in performing all study procedures in the CRU for research participants.

Source of Funding: This research was funded, in part, by 1R01HD057236-01A, clinicaltrials.gov NCT00957476 (SHM, PMC) and the National Institutes of Health (NIH) Clinical and Translational Science Award (CTSA) program led by the NIH's National Center for Advancing Translational Sciences (NCATS) UL1TR000439.

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Figure 1.

Maternal Fat Mass (FM) Accrual with Gestational Weight Gain (GWG).

A. FM vs. GWG. Overall (n=49), $r=0.87$, $p<0.0001$; overweight (n=23), $r=0.72$, $p=0.0001$; obese (n=26), $r=0.93$, $p<0.0001$

B. FM by adherence to 2009 IOM Guidelines for Weight Gain in Pregnancy. Bars represent median FM, kg; FM differs by IOM GWG adherence ($p<0.001$); * represent significant differences in FM accrual in each pairwise comparison ($p<0.001$)

Figure 2.

Maternal Lean Body Mass (LBM) Accrual with Gestational Weight Gain (GWG).

A. LBM vs. GWG. Overall (n=49), $r=0.52$, $p=0.001$; overweight (n=23), $r=0.63$, $p=0.01$; obese (n=26), $r=0.47$, $p=0.02$

B. LBM by adherence to 2009 IOM Guidelines for Weight Gain in Pregnancy. Bars represent median LBM, kg; LBM differs by IOM GWG adherence ($p=0.03$); ** represents significant differences in LBM accrual between inadequate and excess GWG ($p=0.01$)

Table 1

Characteristics of overweight/obese cohort (n=49)

Cohort characteristics	Median [IQR], or n (%)
Maternal age, yrs	26.0 [23-30]
Gestational diabetes	6 (12)
Race/ethnicity	
Caucasian	21 (43)
African-American	17 (35)
Other	11 (22)
Parous	37 (76)
Gestational age at study visits, wks	
Visit 1	14.6 [13-15.4]
Visit 2	35.3 [34.6-35.9]
Body mass index (BMI), kg/m ² , Visit 1	30.3 [28.5-35.2]

Table 2

Adherence to 2009 Institute of Medicine Guidelines for Weight Gain in Pregnancy by BMI class

IOM adherence	Overweight (n=23)	Obese (n=26)
	n (%)	
Inadequate	6 (26)	10 (38)
Adequate	6 (26)	7 (27)
Excess	11 (48)	9 (35)

* Adherence similar by body mass index class (p=0.6)

Table 3

Visit 1 fat mass (FM) and lean body mass (LBM) by subsequent adherence to 2009 Institute of Medicine (IOM) Guidelines for Gestational Weight Gain (GWG) in Pregnancy

Body composition	Inadequate	Adequate	Excess
	Median [IQR]		
Overweight			
FM	27.9 [22.9-30.1]	27.9 [23.4-34.5]	27.4 [23.6-32.6]
LBM	44.5 [41.6-44.9]	41.1 [38.9-48.0]	45.7 [43.2-49.1]
Obese			
FM	47.5 [38.6-58.4]	39.4 [36.1-44.0]	38.2 [31.9-42.6]
LBM	50.5 [45.7-56.0]	56.1 [52.2-59.3]	51.3 [50.0-55.7]

Overweight women have similar Visit 1 FM ($p=1.0$) and LBM ($p=0.2$), and obese women have similar Visit 1 FM ($p=0.2$) and LBM ($p=0.2$) regardless of subsequent adherence to 2009 IOM Guidelines for GWG in Pregnancy