Published in final edited form as:

Am J Obstet Gynecol. 2015 April ; 212(4): 499.e1–499.e12. doi:10.1016/j.ajog.2014.11.012.

Associations of trimester-specific gestational weight gain with maternal adiposity and systolic blood pressure at 3 and 7 years postpartum

Jessica R. Walter, MD,

Research performed at : Harvard Medical School, 25 Shattuck Street, Boston, MA, 02115 USA

Current position: Department of Obstetrics and Gynecology, Northwestern University School of Medicine, jessica.walter@northwestern.edu

Wei Perng, PhD,

Obesity Prevention Program, Department of Population Medicine, Harvard Medical School and Harvard Pilgrim Health Care Institute, 133 Brookline Avenue, Boston, MA, 02215 USA,

wei_perng@gmail.com

Ken P. Kleinman, ScD,

Obesity Prevention Program, Department of Population Medicine, Harvard Medical School and Harvard Pilgrim Health Care Institute, 133 Brookline Avenue, Boston, MA, 02215 USA,

ken.kleinman@gmail.com

Ms. Sheryl L. Rifas-Shiman, MPH,

Obesity Prevention Program, Department of Population Medicine, Harvard Medical School and Harvard Pilgrim Health Care Institute, 133 Brookline Avenue, Boston, MA, 02215 USA,

sheryl_rifas@hphc.org

Janet W. Rich-Edwards, ScD, and

Channing Laboratory and Connors Center for Women's Health and Gender Biology, Brigham and Women's Hospital, One Brigham Circle, 1620 Tremont St Boston MA 02120 USA,

jr33@partners.org

Emily Oken, MD, MPH

Obesity Prevention Program, Department of Population Medicine, Harvard Medical School and Harvard Pilgrim Health Care Institute, 133 Brookline Avenue, Boston, MA, 02215 USA,

emily_oken@hphc.org

© 2014 Elsevier Inc. All rights reserved.

Address all correspondence and reprint requests to: Emily Oken MD, MPH; Department of Population Medicine; 133 Brookline Avenue; Boston, MA 02215 emily_oken@hphc.org. Phone: 617-509-9879. FAX: 617-509-9853.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Conflicts of interest: EO has presented an invited talk on "Effects of maternal obesity on fetal growth and metabolic health of the offspring" for Abbott Nutrition in 2014. The authors report no other conflicts of interest

Presentation at conference: This paper was presented at the 27th Annual meeting of the Society for Pediatric and Perinatal Epidemiologic Research, June 23–24 2014, Seattle, WA.

Abstract

OBJECTIVE—Our objective was to examine the associations of total and trimester-specific gestational weight gain (GWG) rate with postpartum maternal weight and cardiometabolic risk. We hypothesized the first trimester GWG would be most strongly associated with long-term maternal health.

METHODS—We studied 801 women enrolled during the 1st trimester of pregnancy in the Boston-area Project Viva cohort 1999–2002. At 3 years postpartum we measured maternal weight, waist circumference, and systolic blood pressure (SBP) and collected fasting blood from a subset. At 7 years postpartum we again measured weight and waist circumference. We used multivariable linear regression to evaluate relations of total and trimester-specific GWG rate with weight change (vs. self-reported pre-pregnancy weight) and waist circumference at each timepoint, stratified by pre-pregnancy weight, as well as associations with SBP and insulin resistance at 3 years.

RESULTS—Median age at enrollment was 34.0 years (range: 16.4–44.9); 65% were white. Mean (SD) total GWG rate was 0.38 (0.14) kg/week. Women gained weight faster during the second (0.47 [0.19] kg/week) and third trimesters (0.44 [0.22] kg/week) than the first (0.22 [0.22] kg/week). Total and first trimester GWG rate were most strongly associated with postpartum weight change. Among normal weight women, each 1 SD increase in total and first trimester GWG rate corresponded with 0.85 (95% CI: 0.07, 1.63) kg and 2.08 (1.32, 2.84) kg greater weight change at 3 and 7 years postpartum respectively, but there was not strong evidence of association for either second (–0.30 kg; 95% CI: –1.08, 0.48) or third trimester (–0.26 kg; 95% CI: –1.08, 0.55) GWG. First trimester GWG rate also related to 3-year postpartum weight change in overweight (2.28 kg; 95% CI: 0.95, 3.61) and obese (2.47 kg; 95% CI: 0.98, 3.97) women. Greater total and first trimester GWG rate were associated with larger waist circumference and higher SBP but not insulin resistance.

CONCLUSION—In this observational cohort, first trimester weight gain was more strongly associated with maternal weight retention as well as higher waist circumference and blood pressure than 2nd or 3rd trimester gain. Interventions targeting GWG beginning very early in pregnancy may benefit long-term maternal health.

Keywords

Gestational weight gain; cardiometabolic health; postpartum period; pregnancy

INTRODUCTION

An estimated 40% of normal weight women and 60% of overweight women exceed Institute of Medicine (IOM) recommendations for gestational weight gain (GWG).¹ Excess GWG is associated with greater short-term postpartum weight retention and adverse cardiometabolic outcomes for both mother and child, including increased risk of obesity, central adiposity, and higher systolic blood pressure.^{2–8}

Clinicians and researchers typically focus on total GWG.⁹ However, weight gained across specific intervals of pregnancy has differential contributions to maternal, placental, and fetal growth. Greater early GWG is associated with higher risk of pregnancy complications,

including hypertensive disorders of pregnancy,¹⁰ gestational diabetes,^{11,12} and postpartum weight retention,¹³ independent of body mass index (BMI) entering pregnancy. To our knowledge only one study has examined GWG timing with respect to longer-term maternal outcomes.⁵ In that analysis, mid-pregnancy GWG (19–28 weeks) was more strongly related to adiposity and blood pressure at 16 years postpartum, but only among normal weight women.⁵ However, in that UK cohort recruited 1991–2, both maternal BMI (mean 22.5 kg/m²) and GWG (mean 12.6 kg) were substantially lower than is common in the US today, and obese women were not studied separately. Categorizing by pre-pregnancy BMI is both practically important given that current IOM guidelines¹⁴ stratify by pre-pregnancy weight status, and physiologically important given known differences in gestational metabolism between normal weight and obese women.¹⁵

In the present study, we hypothesized that first trimester GWG would be most strongly associated with long-term maternal cardio-metabolic health measures, including overall and central adiposity, SBP, and insulin resistance at 3 and 7 years postpartum.

MATERIALS AND METHODS

Study population

We studied participants from Project Viva, a prospective pre-birth cohort of women enrolled 1999–2002 from Harvard Vanguard Medical Associates, a multispecialty practice in eastern Massachusetts.¹⁶ All women provided written informed consent at each visit and the Harvard Pilgrim Health Care Institutional Review Board approved this study.

Of 2,128 mothers who delivered a live singleton infant, we conducted in-person visits with 1287 at 3 years postpartum (median 3.2 years, range 2.8 to 6.2) and 1107 at 7 years postpartum (median 7.7 years, range 6.6 to 10.9). We excluded from this analysis women who were underweight entering pregnancy (BMI <18.5 kg/m²) because of insufficient sample size for stratified analysis, or who had an intervening pregnancy after the index delivery, which might affect outcomes, which left 741 eligible participants in the 3-year analysis and 525 women in the 7-year analysis. The 801 women total (some women were included at both visits) were similar to those excluded although the analyzed cohort was slightly older (mean age 34 vs. 31 years), had higher pre-pregnancy BMI (~1.2 kg/m²), and accordingly gained less total weight during pregnancy (0.9 kg).

Exposure: total and trimester-specific GWG rate

Women reported their pre-pregnancy weight at study enrollment. We obtained serial clinical weights from prenatal records, with a median of 13 (3 to 28) repeated measurements per woman. We calculated total GWG rate as the difference between the last clinically measured weight (within 4 weeks prior to delivery) and self-reported pre-pregnancy weight divided by gestation length in weeks. Since literature varies for specific periods of GWG,^{5,17} we took a data-driven approach to identify population-specific cut-off points that demarcate significant differences in GWG rate throughout pregnancy. Using methods described by Fraser et al.,⁵ we identified linear slope changes at 15 and 28 weeks gestational age. However, these time points were not substantially superior to those used for trimester cut-

offs, so we proceeded with more clinically-relevant trimesters. We defined first trimester as the date of last menstrual period to day 91, second trimester as day 91 to day 182, and third trimester day 182 to the date of delivery. We performed linear interpolation between the two closest weight measures to estimate weight at day 91 and day 182 and calculated trimester-specific GWG rates (kg/week) for each period.

Postpartum health outcomes

During in-person 3-year postpartum visits, trained research assistants (RAs) measured women's weight to the nearest 0.1 kg using an electronic scale (model 881; Seca Corp., Hanover, MD); waist circumference (WC) to the nearest 1 mm using a non-stretchable measuring tape; and SBP 5 times, 1 minute apart, with a Dinamap (Critikon, Inc., Tampa, FL) Pro 100. Phlebotomists collected blood specimens, which were processed within 24 hours. We assayed glucose and insulin from plasma only from women who were fasting at least 12 hours at the time of the visit ($n = 181$); we did not require that all women attend the visit in a fasted state. We used the homeostasis model to estimate insulin resistance from these samples: $\text{HOMA-IR} = (\text{fasting insulin } [\mu\text{U/mL}] \times \text{fasting glucose } [\text{mmol/L}]) / 22.5$. At the 7-year visit, RAs again measured weight (Tanita scale model TBF-300A, Tanita Corporation of America, Inc., Arlington Heights, IL) and WC, but not blood pressure and did not collect blood, as we did not have funding at this visit to assess maternal outcomes. We calculated postpartum weight change as the difference between weight at each time point (3 or 7 years postpartum) and pre-pregnancy weight.

Assessment of covariates

At enrollment and the mid-pregnancy visit, women completed questionnaires and interviews inquiring about race, ethnicity, education, parity, lifestyle characteristics including smoking habits, diet, and physical activity.¹⁶ We calculated pre-pregnancy BMI using self-reported pre-pregnancy weight and height. Medical records provided prenatal glucose tolerance status,¹⁸ delivery date, and infant sex. Mothers reported breastfeeding duration in postpartum questionnaires.

Data analysis

First, in bivariate analyses, we evaluated the distributions of total weight gain rate and gain in each trimester across categories of sociodemographic, anthropometric, perinatal, and lifestyle characteristics to identify potential confounders of the association of GWG rate with postpartum outcomes. We assessed their significance using the Wald chi-square test for categorical variables and a test for linear trend for ordinal variables.

Next, we examined the relations of total and trimester-specific weight gain rate with change in weight and WC by 3 and 7 years postpartum using multivariable linear regression models. We conducted separate analyses for normal weight (BMI 18.5–24.9 kg/m²), overweight (BMI 25.0–29.9 kg/m²), and obese (BMI ≥ 30 kg/m²) women in light of evidence of an interaction (P -interaction < 0.05) between pre-pregnancy weight status and GWG rate for the anthropometric outcomes. We quantified the difference and 95% confidence interval (CI) in each postpartum outcome according to quintiles of total and trimester-specific GWG rate. Because the associations were generally linear and monotonic, we opted to examine

GWG rate continuously, scaled to a 1 standard deviation (SD) increment to optimize power. In our base model (Model 1), we accounted for confounders including age, race, education, pre-pregnancy BMI, parity and partner's BMI. We adjusted for GWG rate in the previous period(s) when second or third trimester GWG rate was the exposure of interest. Unadjusted results are not presented since they were not notably different from base model results. We then additionally adjusted for pregnancy smoking habits, gestational glucose tolerance, child's sex, and breastfeeding duration (Model 2). Covariate selection was based on bivariate associations and *a priori* knowledge of GWG predictors. All models met assumptions for linear regression.

For cardiometabolic outcomes (SBP and HOMA-IR) at 3 years postpartum, we examined associations among all women because associations did not differ by pre-pregnancy weight status (P -interaction>0.10 for all models). We accounted for the same set of covariates as described above for Model 1 and 2, but we also included a third model (Model 3) that accounted for current adiposity (BMI at 3 years postpartum). In models for HOMA-IR, we excluded women with type I and type II diabetes, or gestational diabetes mellitus (GDM) which can influence both patterns of weight gain¹¹ and postpartum hyperglycemia.^{19,20}

Adjustment for physical activity before pregnancy, and adherence to the prudent or Western dietary patterns²¹ during early pregnancy did not change results so they were not included in the final models. We conducted sensitivity analyses excluding preterm births (gestational age <37 weeks; $n = 56$) and women with preeclampsia ($n = 26$) and observed no substantial differences in our findings.

Some subjects were missing covariate information (Supplemental Table 1), so we used chained equations in SAS PROC MI to impute values for these covariates.²² To avoid incorrect imputations, all Project Viva subjects were used in generating imputed values. We generated 50 imputed datasets and our reported results combine the estimates across the results.²³ We included only participants with observed, non-imputed outcomes. The results from analyses using imputed data were not materially different from those using original data (data not shown). All analyses were performed using SAS software (version 9.3; SAS Institute Inc., Cary, NC).

RESULTS

Median age at enrollment was 34.0 years (range: 16.4, 44.9) and 65.4% of women were white. Mean (SD) total GWG was 15.0 (5.6) kg over 39.4 (1.9) weeks gestation, or an average gain of 0.38 (0.14) kg/week throughout pregnancy. Women gained weight at faster rates during the second (6.1 [2.5] kg at 0.47 [0.19] kg/week) and third trimesters (6.0 [2.9] kg at 0.44 [0.22] kg/week) than in the first (2.9 [2.9] kg at 0.22 [0.22] kg/week). The mean rate of GWG for normal, overweight, and obese women in the cohort exceeded 2009 IOM recommendations¹⁴ for the second and third trimesters (Table 1).

Associations of GWG rate with sociodemographic and behavioral characteristics differed by trimester (Table 2). Second and third trimester GWG rate varied with many sociodemographic characteristics including maternal age (third trimester), marital status and

race/ethnicity (second trimester), education and household income (both). In contrast, first trimester GWG rate did not vary with these characteristics, but was associated with behaviors including smoking, pre-pregnancy physical activity, and diet pattern. GWG rate varied across pre-pregnancy BMI categories for second and third trimester gain, but not for first trimester gain.

In adjusted regression models, the rate of first trimester GWG was more strongly associated with postpartum weight change and WC than rate of gain in either of the other two trimesters, regardless of pre-pregnancy weight status (Figure 1). Results for second and third trimester gain were similar even without adjustment for weight gain in the previous period(s) (data not shown). Associations of total GWG rate with both weight change and WC followed similar trends to those of the first trimester, more so than the second and third trimesters at both 3 and 7 years postpartum (Figure 1). Additional adjustment for smoking, gestational glucose tolerance, offspring sex, and breastfeeding duration did not attenuate associations (Supplemental Tables 2 and 3).

For women at normal weight women entering pregnancy, each 1 SD increment in first trimester GWG rate (0.22 kg/week) corresponded with 2.08 (95% CI: 1.32, 2.84) kg greater weight change from pre-pregnancy to 3 years postpartum. Associations were null for both second trimester gain (−0.30; −1.08, 0.48 per 0.19 kg/week) and third trimester gain (−0.26; −1.08, 0.55 per 0.22 kg/week). Patterns were similar for WC, such that normal weight women had 1.70 (0.96, 2.44) cm greater WC for each 1 SD increase in first trimester GWG rate, compared to 0.16 (−0.60, 0.92) cm per 19 kg/week and 0.82 (−0.03, 1.62) per 0.22 kg/week for second and third trimester gains, respectively. Similarly, first trimester GWG rate was most strongly associated with both weight change and WC at 3 years postpartum among overweight and obese women (Supplemental Table 3).

The differences in associations of early GWG with maternal outcomes between normal, overweight, and obese became more apparent at 7 years postpartum. Among normal weight women, GWG in all trimesters was associated with weight change and WC, although the relation was strongest for first trimester rate of gain (Supplemental Tables 2 and 3). In overweight women only first trimester gain was associated with weight change, but in obese women, second trimester GWG was most strongly associated.

After accounting for confounders, first trimester GWG was directly related to SBP (1.48 [0.69, 2.27] mmHg per 0.22 kg/wk), but not second or third trimester GWG (Table 3). The association between total GWG and SBP (0.93 [0.10, 1.76] mmHg per 0.14 kg/wk) persisted after accounting for potential mediating characteristics during the peripartum period (Table 3 Model 2), but was attenuated to null after accounting for BMI at 3 years, whereas first trimester GWG remained associated with 3-year postpartum SBP in all models. Neither total nor trimester-specific GWG rate was related to HOMA-IR at 3 years postpartum among the smaller subset of women who provided fasting blood samples.

Among 343 Project Viva mothers who had weight recorded in the medical record in the 3 months before their last menstrual period, mean underreporting of self-reported pre-pregnancy weight was ~1 kg, but the correlation between self-reported and clinically

measured weight was very high ($r=0.997$) and underreporting was non-differential with respect to pre-pregnancy BMI, gestational age at enrollment, and race/ethnicity. We evaluated the potential impact of underreporting pre-pregnancy weight by examining the relations of first trimester weight gain with outcomes after adding 1 kg to the self-reported values. Using the corrected values attenuated the magnitude of associations by about 1/3, but did not change the overall trends or significance of first trimester or total GWG rate (data not shown).

DISCUSSION

Our finding that first trimester weight gain was most strongly associated with postpartum maternal cardio-metabolic outcomes has a likely mechanistic explanation, as weight gain early in pregnancy primarily represents maternal fat deposition rather than fetal or placental tissue or fluid gain.^{11,14,24,25} Excess fat has been hypothesized to predispose women to perinatal insulin resistance, and this risk may extend to the postpartum period.²⁵ While other studies have shown that excess early GWG is independently associated with greater postpartum weight retention in women as early as 6 weeks after delivery,^{5,13} our findings demonstrate these relationships persist for at least 7 years.

The direct relationship between first trimester GWG and postpartum weight retention was strongest among normal weight women by 7 years postpartum, whereas at 3 years postpartum the association was strongest among obese women. Fraser et al.⁵ observed that greater mid-pregnancy GWG (19–28 weeks) was associated with higher central adiposity and blood pressure among normal weight women at 16 years postpartum. The consistent observation between our results and the Fraser et al. study that normal weight women are most sensitive to higher GWG has a physiological basis. In early pregnancy, there is an increase in insulin sensitivity facilitating greater lipogenesis and fat storage in anticipation of future placental and fetal needs.¹⁵ Normal weight women often experience a larger increase in fat stores during pregnancy than obese women, who are already more insulin resistant at baseline.^{15,26} Therefore, normal weight women are at the greatest risk to accumulate fat with excess early gestational weight gain. Furthermore, the weight that obese women gain is more likely fluid and non-fat tissue, which may be easier to lose following delivery.^{1,27,28}

We also found that a greater first trimester GWG rate was related to higher SBP at 3 years postpartum. While this finding is supported by the ALSPAC data,⁵ another study of 478 women from Pittsburgh reported no association between total GWG and SBP at 8 years postpartum,⁶ perhaps because total GWG incorporates both early GWG, which was directly related to SBP, as well as later GWG, which was not. In our study, GWG rate was not related to HOMA-IR, perhaps because of the relatively short postpartum follow-up period that may fail to capture the natural time course of developing insulin resistance, or the smaller sample size for this outcome.

Interestingly, sociodemographic characteristics were not associated with first trimester GWG. Instead, the rate of early GWG was only related to maternal behaviors such as smoking, greater pre-pregnancy physical activity, and prudent diet. Although smoking status

is a widely recognized contributor to metabolic dysfunction, our results regarding pre-pregnancy physical activity and diet are counterintuitive: adherence to a prudent diet and greater pre-pregnancy physical activity were associated with greater early GWG rate. It may be that women who exercise more and eat a healthier diet are also more insulin sensitive, leading to easier weight gain. Nevertheless, our results broadly suggest early GWG is more strongly influenced by modifiable behaviors rather than immutable characteristics, raising the possibility that interventions commencing before or very early in pregnancy might be more successful in influencing early GWG and thereby have a long-lasting impact on maternal health.

COMMENT

In this study of reproductive-aged women with prospectively collected information on perinatal characteristics, research-quality measures of anthropometry and cardiometabolic biomarkers at 3 and 7 years postpartum, and rich data on potential confounders and mediators, we found differential associations of trimester-specific weight gain rate with long-term maternal health. Specifically, higher rates of weight gain during the first trimester were consistently related to greater maternal adiposity and higher SBP, whereas weight gain in the other trimesters was not associated with these postpartum outcomes.

This study has several limitations. First, pre-pregnancy BMI was based on self-reported weight and may suffer reporting bias. However, self-reported and clinically measured pre-pregnancy weights were highly correlated and the magnitude of underreporting was not associated with key characteristics, including pre-pregnancy weight status. Any remaining bias is likely non-differential. Also, our sensitivity analysis adding 1 kg to pre-pregnancy weight showed similar results. Second, we cannot rule out the possibility that GWG rate, especially during the first trimester, are driven by weight gain patterns and fat distribution prior to pregnancy. Third, as with all cohort studies, attrition bias may be an issue. In this study, many baseline characteristics were similar between participants included in the study and those lost to follow-up. Fourth, we restricted the sample to women without intervening pregnancies who, in addition to being older, may be inherently different from their counterparts in immeasurable ways; thus, limiting generalizability of our findings to all reproductive-aged women. Finally, we were unable to examine associations in underweight women due to insufficient sample size, and numbers with the HOMA outcome were small, limiting power for those models.

In conclusion, greater rate of GWG during early pregnancy corresponded with greater postpartum weight change, WC, and SBP. While additional work is required to evaluate the potential impact of moderating early GWG on long-term health, including child health, our findings suggest a potential role for targeted interventions that emphasize healthy weight gain in early pregnancy.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Sources of funding:

This work was supported by the U.S. National Institutes of Health (R01 HD34568, R01 HL064925 R21 DK073739, P30 DK092924, and K24 HD069408), and the Harvard Pilgrim Health Care Institute. The funders had no role in study design; in the collection, analysis or interpretation of data; in the writing of the report; or in the decision to submit the article for publication.

Abbreviations

BMI	body mass index
GWG	gestational weight gain
IOM	Institute of Medicine;

REFERENCES

1. Chu SY, Callaghan WM, Bish CL, D'Angelo D. Gestational weight gain by body mass index among US women delivering live births, 2004–2005: fueling future obesity. *American Journal of Obstetrics and Gynecology*. 2009 Mar;200(3):271. e271–277. [PubMed: 19136091]
2. Rooney BL, Schauburger CW, Mathiason MA. Impact of perinatal weight change on long-term obesity and obesity-related illnesses. *Obstetrics and Gynecology*. 2005 Dec; 106(6):1349–1356. [PubMed: 16319262]
3. Mamun AA, Kinarivala M, O'Callaghan MJ, Williams GM, Najman JM, Callaway LK. Associations of excess weight gain during pregnancy with long-term maternal overweight and obesity: evidence from 21 y postpartum follow-up. *The American Journal of Clinical Nutrition*. 2010 May; 91(5):1336–1341. [PubMed: 20237138]
4. Amorim AR, Rossner S, Neovius M, Lourenco PM, Linne Y. Does excess pregnancy weight gain constitute a major risk for increasing long-term BMI? *Obesity (Silver Spring)*. 2007 May; 15(5):1278–1286. [PubMed: 17495204]
5. Fraser A, Tilling K, Macdonald-Wallis C, et al. Associations of gestational weight gain with maternal body mass index, waist circumference, and blood pressure measured 16 y after pregnancy: the Avon Longitudinal Study of Parents and Children (ALSPAC). *The American Journal of Clinical Nutrition*. 2011 Jun; 93(6):1285–1292. [PubMed: 21471282]
6. McClure CK, Catov JM, Ness R, Bodnar LM. Associations between gestational weight gain and BMI, abdominal adiposity, and traditional measures of cardiometabolic risk in mothers 8 y postpartum. *The American Journal of Clinical Nutrition*. 2013 Nov; 98(5):1218–1225. [PubMed: 24047920]
7. Fraser A, Tilling K, Macdonald-Wallis C, et al. Association of maternal weight gain in pregnancy with offspring obesity and metabolic and vascular traits in childhood. *Circulation*. 2010 Jun 15; 121(23):2557–2564. [PubMed: 20516377]
8. Oken E, Taveras EM, Kleinman KP, Rich-Edwards JW, Gillman MW. Gestational weight gain and child adiposity at age 3 years. *Am J Obstet Gynecol*. 2007 Apr;196(4):322. e321–328. PMID: PMC1899090. [PubMed: 17403405]
9. American College of O, Gynecologists. ACOG Committee opinion no. 549: obesity in pregnancy. *Obstetrics and Gynecology*. 2013 Jan; 121(1):213–217. [PubMed: 23262963]
10. Macdonald-Wallis C, Tilling K, Fraser A, Nelson SM, Lawlor DA. Gestational weight gain as a risk factor for hypertensive disorders of pregnancy. *American Journal of Obstetrics and Gynecology*. 2013 Oct;209(4):327. e321–317. [PubMed: 23711667]
11. Morisset AS, Tchernof A, Dube MC, Veillette J, Weisnagel SJ, Robitaille J. Weight gain measures in women with gestational diabetes mellitus. *Journal of Women's Health*. 2011 Mar; 20(3):375–380.

12. Carreno CA, Clifton RG, Hauth JC, et al. Excessive early gestational weight gain and risk of gestational diabetes mellitus in nulliparous women. *Obstetrics and Gynecology*. 2012 Jun; 119(6): 1227–1233. [PubMed: 22617588]
13. Muscati SK, Gray-Donald K, Koski KG. Timing of weight gain during pregnancy: promoting fetal growth and minimizing maternal weight retention. *International journal of obesity and related metabolic disorders : journal of the International Association for the Study of Obesity*. 1996 Jun; 20(6):526–532.
14. Rasmussen, KM.; Yaktine, AL. *Weight Gain During Pregnancy: Reexamining the Guidelines*. Washington (DC): 2009.
15. Lain KY, Catalano PM. Metabolic changes in pregnancy. *Clinical obstetrics and gynecology*. 2007 Dec; 50(4):938–948. [PubMed: 17982337]
16. Oken E, Baccarelli A, Gold D, Kleinman K, Litonjua A, De Meo E. Cohort profile: Project Viva. *International journal of epidemiology*. In Press.
17. Kleinman KP, Oken E, Radesky JS, Rich-Edwards JW, Peterson KE, Gillman MW. How should gestational weight gain be assessed? A comparison of existing methods and a novel method, area under the weight gain curve. *Int J Epidemiol*. 2007 Dec; 36(6):1275–1282. [PubMed: 17715174]
18. Regnault N, Gillman MW, Rifas-Shiman SL, Eggleston E, Oken E. Sex-specific associations of gestational glucose tolerance with childhood body composition. *Diabetes Care*. 2013 Oct; 36(10): 3045–3053. [PubMed: 23877978]
19. Hanna FW, Peters JR. Screening for gestational diabetes; past, present and future. *Diabetic Medicine*. 2002 May; 19(5):351–358. [PubMed: 12027921]
20. Bellamy L, Casas JP, Hingorani AD, Williams D. Type 2 diabetes mellitus after gestational diabetes: a systematic review and meta-analysis. *Lancet*. 2009 May 23; 373(9677):1773–1779. [PubMed: 19465232]
21. Radesky JS, Oken E, Rifas-Shiman SL, Kleinman KP, Rich-Edwards JW, Gillman MW. Diet during early pregnancy and development of gestational diabetes. *Paediatr Perinat Epidemiol*. 2008 Jan; 22(1):47–59. [PubMed: 18173784]
22. White I, Royston P, Wood A. Multiple imputation using chained equations: issues and guidance for practice. *Statistical Medicine*. 2011; 30(4):377–399.
23. Rubin, D. *Multiple imputation for nonresponse in surveys*. Hoboken, NJ: Wiley-Interscience; 2004.
24. van Raaij JM, Peek ME, Vermaat-Miedema SH, Schonk CM, Hautvast JG. New equations for estimating body fat mass in pregnancy from body density or total body water. *The American Journal of Clinical Nutrition*. 1988 Jul; 48(1):24–29. [PubMed: 3389327]
25. Hedderson MM, Gunderson EP, Ferrara A. Gestational weight gain and risk of gestational diabetes mellitus. *Obstetrics and Gynecology*. 2010 Mar; 115(3):597–604. [PubMed: 20177292]
26. Ehrenberg HM, Huston-Presley L, Catalano PM. The influence of obesity and gestational diabetes mellitus on accretion and the distribution of adipose tissue in pregnancy. *Am J Obstet Gynecol*. 2003 Oct; 189(4):944–948. [PubMed: 14586331]
27. Kac G, Benicio MH, Velasquez-Melendez G, Valente JG. Nine months postpartum weight retention predictors for Brazilian women. *Public Health Nutrition*. 2004 Aug; 7(5):621–628. [PubMed: 15251052]
28. Lederman SA, Paxton A, Heymsfield SB, Wang J, Thornton J, Pierson RN Jr. Body fat and water changes during pregnancy in women with different body weight and weight gain. *Obstetrics and Gynecology*. 1997 Oct; 90(4 Pt 1):483–488. [PubMed: 9380301]

Figure 1.

Adjusted associations of trimester-specific GWG rates (1st trimester: per 0.22 kg/week) with postpartum weight change and waist circumference. All associations represent are adjusted for mother's age, parity, race, education, pre-pregnancy BMI, and partner's BMI (Model 1). Estimates for 2nd and 3rd trimester GWG are also adjusted for GWG rate from previous trimester(s).

Table 1

Rates of total and trimester-specific gestational weight gain among 801 women in Project Viva, and as recommended in 2009 Institute of Medicine (IOM) guidelines

	Observed in Project Viva		IOM guidelines ^a
	Mean	Range	Range
Total GWG rate (kg/week)			
Normal weight (BMI 18.5–24.9)	0.39	0.08 to 0.78	0.28 to 0.40
Overweight (BMI 25–29.9)	0.40	0.06 to 0.86	0.17 to 0.28
Obese (BMI ≥30)	0.30	−0.19 to 0.76	0.12 to 0.23
1st trimester GWG rate (kg/week)			
Normal weight (BMI 18.5–24.9)	0.22	−0.67 to 1.08	0.04 to 0.15
Overweight (BMI 25–29.9)	0.24	−0.69 to 1.20	0.04 to 0.15
Obese (BMI ≥30)	0.21	−0.63 to 1.22	0.04 to 0.15
2nd trimester GWG rate (kg/week)			
Normal weight (BMI 18.5–24.9)	0.51	0.04 to 1.06	0.36 to 0.45
Overweight (BMI 25–29.9)	0.50	0.01 to 1.20	0.23 to 0.32
Obese (BMI ≥30)	0.31	−0.41 to 0.97	0.18 to 0.27
3rd trimester GWG rate (kg/week)			
Normal weight (BMI 18.5–24.9)	0.45	−0.24 to 0.98	0.36 to 0.45
Overweight (BMI 25–29.9)	0.46	−0.34 to 1.15	0.23 to 0.32
Obese (BMI ≥30)	0.39	−0.45 to 1.00	0.18 to 0.27

^aValues are adapted from the Institute of Medicine 2009 recommendations (14).

Table 2
Rates of total and trimester-specific gestational weight gain (GWG) according to characteristics of 801 Project Viva mothers

	N(%)	Mean $\pm$ SD rate of GWG (kg/week)			
		Total	1st trimester (0–13 wks)	2nd trimester (14–26 wks)	3rd trimester (27 wks)
Overall	801	0.38 $\pm$ 0.14	0.22 $\pm$ 0.22	0.47 $\pm$ 0.19	0.44 $\pm$ 0.22
Sociodemographic characteristics					
Age at enrollment					
15–24 years	61 (8%)	0.40 $\pm$ 0.16	0.20 $\pm$ 0.31	0.48 $\pm$ 0.22	0.50 $\pm$ 0.25
25–34 years	403 (50%)	0.38 $\pm$ 0.15	0.22 $\pm$ 0.24	0.47 $\pm$ 0.21	0.45 $\pm$ 0.22
35–44 years	337 (42%)	0.37 $\pm$ 0.13	0.23 $\pm$ 0.19	0.47 $\pm$ 0.18	0.42 $\pm$ 0.21
<i>P</i> trend ^a		0.25	0.36	0.83	0.003
Marital status					
Married/cohabitating	725 (91%)	0.38 $\pm$ 0.14	0.22 $\pm$ 0.22	0.47 $\pm$ 0.19	0.44 $\pm$ 0.22
Single	76 (9%)	0.37 $\pm$ 0.17	0.24 $\pm$ 0.27	0.41 $\pm$ 0.25	0.45 $\pm$ 0.25
<i>p</i> ^b		0.39	0.60	0.01	0.82
Race/ethnicity					
Black	142 (18%)	0.36 $\pm$ 0.15	0.23 $\pm$ 0.29	0.42 $\pm$ 0.23	0.42 $\pm$ 0.24
Hispanic	65 (8%)	0.36 $\pm$ 0.16	0.23 $\pm$ 0.29	0.44 $\pm$ 0.21	0.40 $\pm$ 0.26
White	524 (65%)	0.39 $\pm$ 0.14	0.22 $\pm$ 0.19	0.48 $\pm$ 0.19	0.46 $\pm$ 0.21
Asian	35 (4%)	0.36 $\pm$ 0.09	0.20 $\pm$ 0.17	0.45 $\pm$ 0.11	0.45 $\pm$ 0.21
Other	35 (4%)	0.41 $\pm$ 0.16	0.27 $\pm$ 0.33	0.49 $\pm$ 0.18	0.47 $\pm$ 0.22
<i>p</i> ^b		0.11	0.53	0.01	0.13
Annual household income					
< \$20,000	51 (6%)	0.37 $\pm$ 0.18	0.23 $\pm$ 0.37	0.43 $\pm$ 0.25	0.44 $\pm$ 0.27
\$20,000 – \$39,999	92 (11%)	0.35 $\pm$ 0.18	0.23 $\pm$ 0.31	0.42 $\pm$ 0.24	0.39 $\pm$ 0.26
\$40,000 – \$69,999	180 (22%)	0.37 $\pm$ 0.16	0.22 $\pm$ 0.27	0.45 $\pm$ 0.24	0.45 $\pm$ 0.24
\$70,000 – 100,000	173 (22%)	0.37 $\pm$ 0.14	0.22 $\pm$ 0.19	0.48 $\pm$ 0.20	0.41 $\pm$ 0.23
> \$100,000	306 (38%)	0.40 $\pm$ 0.12	0.23 $\pm$ 0.19	0.49 $\pm$ 0.17	0.48 $\pm$ 0.20
<i>P</i> trend ^a		0.003	0.87	0.0003	0.02
Education					

	Mean ± SD rate of GWG (kg/week)				
	N(%)	Total	1st trimester (0–13 wks)	2nd trimester (14–26 wks)	3rd trimester (27 wks)
Primary	75 (9%)	0.35 ± 0.15	0.22 ± 0.29	0.43 ± 0.23	0.40 ± 0.21
Secondary	486 (61%)	0.38 ± 0.15	0.22 ± 0.23	0.47 ± 0.21	0.44 ± 0.24
University	240 (30%)	0.39 ± 0.12	0.22 ± 0.18	0.48 ± 0.16	0.46 ± 0.19
<i>P</i> trend ^a		0.08	0.89	0.05	0.05
Smoking habits					
Never	558 (70%)	0.38 ± 0.14	0.22 ± 0.22	0.47 ± 0.18	0.44 ± 0.21
Quit before pregnancy	155 (19%)	0.38 ± 0.14	0.22 ± 0.21	0.47 ± 0.21	0.45 ± 0.24
Smoked in early pregnancy	88 (11%)	0.40 ± 0.16	0.28 ± 0.26	0.46 ± 0.23	0.45 ± 0.24
<i>p</i> ^b		0.64	0.02	0.92	0.81
Partner s BMI (kg/m ²)					
Not overweight (<25 kg/m ²)	283 (35%)	0.39 ± 0.13	0.23 ± 0.21	0.48 ± 0.19	0.45 ± 0.22
Overweight (≥ 25 kg/m ²)	518 (65%)	0.38 ± 0.15	0.22 ± 0.24	0.46 ± 0.20	0.44 ± 0.23
<i>p</i> ^b		0.39	0.79	0.14	0.91

	Mean ± SD rate of GWG (kg/week)				
	N(%)	Total	1st trimester (0–13 wks)	2nd trimester (14–26 wks)	3rd trimester (27 wks)
Perinatal characteristics					
Pre-pregnancy BMI (kg/m ²)					
Normal (18.5– 24.9 kg/m ²)	454 (57%)	0.39 ± 0.11	0.22 ± 0.18	0.51 ± 0.15	0.45 ± 0.19
Overweight (25.0–29.9 kg/m ²)	195 (24%)	0.40 ± 0.14	0.24 ± 0.24	0.50 ± 0.19	0.46 ± 0.24
Obese (≥ 30.0 kg/m ²)	152 (19%)	0.30 ± 0.19	0.21 ± 0.31	0.31 ± 0.25	0.39 ± 0.28
<i>P</i> trend ^a		<0.0001	0.91	<0.0001	0.01
Parity					
0	234 (29%)	0.39 ± 0.14	0.23 ± 0.21	0.48 ± 0.20	0.47 ± 0.22
1	368 (46%)	0.38 ± 0.14	0.22 ± 0.23	0.46 ± 0.19	0.45 ± 0.21
2	199 (25%)	0.37 ± 0.14	0.23 ± 0.24	0.47 ± 0.20	0.41 ± 0.23
<i>P</i> trend ^a		0.10	0.86	0.71	0.001
Gestational glucose tolerance					

	N(%)	Mean $\pm$ SD rate of GWG (kg/week)			
		Total	1st trimester (0–13 wks)	2nd trimester (14–26 wks)	3rd trimester (27 wks)
Normoglycemic	648 (81%)	0.39 $\pm$ 0.14	0.22 $\pm$ 0.22	0.48 $\pm$ 0.19	0.46 $\pm$ 0.20
Isolated hyperglycemia	82 (10%)	0.35 $\pm$ 0.15	0.21 $\pm$ 0.23	0.44 $\pm$ 0.20	0.40 $\pm$ 0.24
Impaired glucose tolerance	32 (4%)	0.40 $\pm$ 0.16	0.30 $\pm$ 0.27	0.48 $\pm$ 0.24	0.41 $\pm$ 0.27
Gestational diabetes	39 (5%)	0.31 $\pm$ 0.16	0.25 $\pm$ 0.25	0.39 $\pm$ 0.22	0.29 $\pm$ 0.34
<i>P</i> trend ^a		0.003	0.20	0.02	<0.0001
Offspring sex					
Male	412 (51%)	0.39 $\pm$ 0.14	0.23 $\pm$ 0.23	0.48 $\pm$ 0.20	0.46 $\pm$ 0.23
Female	389 (49%)	0.37 $\pm$ 0.14	0.22 $\pm$ 0.22	0.46 $\pm$ 0.19	0.43 $\pm$ 0.21
<i>p</i> ^b		0.02	0.36	0.12	0.05
Prudent dietary pattern					
Q1 (lowest)	199 (25%)	0.38 $\pm$ 0.15	0.20 $\pm$ 0.27	0.47 $\pm$ 0.20	0.46 $\pm$ 0.23
Q2	201 (25%)	0.37 $\pm$ 0.15	0.20 $\pm$ 0.21	0.47 $\pm$ 0.22	0.44 $\pm$ 0.22
Q3	200 (25%)	0.38 $\pm$ 0.15	0.22 $\pm$ 0.21	0.47 $\pm$ 0.20	0.45 $\pm$ 0.24
Q4 (highest)	201 (25%)	0.39 $\pm$ 0.15	0.28 $\pm$ 0.25	0.47 $\pm$ 0.19	0.43 $\pm$ 0.24
<i>P</i> trend ^a		0.19	0.001	0.72	0.21
Pre-pregnancy physical activity					
Q1 (lowest)	169 (21%)	0.35 $\pm$ 0.15	0.18 $\pm$ 0.25	0.44 $\pm$ 0.21	0.43 $\pm$ 0.22
Q2	178 (22%)	0.40 $\pm$ 0.13	0.23 $\pm$ 0.23	0.49 $\pm$ 0.20	0.48 $\pm$ 0.21
Q3	244 (30%)	0.39 $\pm$ 0.14	0.24 $\pm$ 0.21	0.47 $\pm$ 0.20	0.45 $\pm$ 0.23
Q4 (highest)	210 (26%)	0.38 $\pm$ 0.16	0.24 $\pm$ 0.26	0.48 $\pm$ 0.21	0.42 $\pm$ 0.25
<i>P</i> trend ^a		0.12	0.01	0.19	0.47

^aFrom a test for linear trend in which the ordinal predictor is entered into the model as a continuous variable.

^bFrom the Wald chi-squared test.

Table 3

Associations of total and trimester-specific rate of gestational weight gain (GWG) with maternal cardiometabolic outcomes among Project Viva moms at 3 years postpartum

		Difference (95% CI)			
		per 1 SD total GWG rate ^a	per 1 SD first trimester GWG rate ^b	per 1 SD second trimester GWG rate ^c	per 1 SD third trimester GWG rate ^d
SSBP (mmHg)					
(n = 741)	Model 1	0.93 (0.10, 1.76)	1.48 (0.69, 2.27)	0.04 (−0.81, 0.90)	−0.08 (−1.01, 0.84)
	Model 2	1.00 (0.16, 1.84)	1.49 (0.69, 2.30)	0.09 (−0.77, 0.94)	−0.01 (−0.95, 0.93)
	Model 3	0.69 (−0.17, 1.54)	1.14 (0.31, 1.97)	0.02 (−0.84, 0.87)	−0.07 (−1.00, 0.86)
HOMA-IR^f					
(n = 167)	Model 1	−0.03 (−0.14, 0.07)	−0.04 (−0.14, 0.06)	0.02 (−0.09, 0.13)	−0.06 (−0.18, 0.06)
	Model 2	−0.01 (−0.11, 0.10)	−0.03 (−0.13, 0.08)	0.03 (−0.08, 0.14)	−0.04 (−0.17, 0.09)
	Model 3	−0.03 (−0.14, 0.08)	−0.06 (−0.16, 0.05)	0.02 (−0.09, 0.13)	−0.04 (−0.16, 0.09)

Model 1: Model 1 + age, race/ethnicity, parity, education, pre-pregnancy BMI, and partner's BMI. Estimates for second and third trimester GWG are also adjusted for GWG rate from previous trimester(s).

Model 2: Model 1 + smoking habits during pregnancy, gestational glucose tolerance, offspring sex, and breastfeeding duration.

Model 3: Model 2 + BMI at 3 years

^a 1 SD = 0.14 kg/week

^b 1 SD = 0.22 kg/week

^c 1 SD = 0.19 kg/week

^d 1 SD = 0.22 kg/week

^e Natural-log transformed

HOMA-IR due to non-normal distributions. Participants with gestational, Type 1, or Type 2 diabetes were excluded from the HOMA-IR results.