HHS Public Access
Author manuscript
Int J Obes (Lond). Author manuscript; available in PMC 2021 September 03.

Published in final edited form as:
Int J Obes (Lond). 2021 July ; 45(7): 1382–1391. doi:10.1038/s41366-021-00792-8.

Pregnancy weight gain in twin gestations and maternal and child health outcomes at 5 years

Lisa M. Bodnar[1,2,3,*], **Abigail R. Cartus**[1], **Sara M. Parisi**[1], **Barbara Abrams**[4], **Katherine P. Himes**[2,3], **Cara L. Eckhardt**[5], **Betty Braxter**[6], **Jennifer A. Hutcheon**[7]

[1]Department of Epidemiology, Graduate School of Public Health, University of Pittsburgh, Pittsburgh, Pennsylvania, United States.

[2]Department of Obstetrics, Gynecology, and Reproductive Sciences, School of Medicine, University of Pittsburgh, Pittsburgh, Pennsylvania, United States.

[3]Magee-Womens Research Institute, Pittsburgh, Pennsylvania, United States.

[4]Division of Epidemiology and Biostatistics, School of Public Health, University of California at Berkeley, Berkeley, California, United States.

[5]Oregon Health Sciences University-Portland State University School of Public Health, Portland, Oregon, United States.

[6]School of Nursing, University of Pittsburgh, Pittsburgh, Pennsylvania, United States.

[7]Department of Obstetrics and Gynaecology, University of British Columbia, Vancouver, Canada.

Abstract

Objective: Current guidelines for maternal weight gain in twin pregnancy were established in the absence of evidence on its longer-term consequences for maternal and child health. We evaluated the association between weight gain in twin pregnancies and the risk of excess maternal postpartum weight increase, childhood obesity, and child cognitive ability.

Methods: We used 5-year follow-up data from 1000 twins born to 450 mothers in the Early Childhood Longitudinal Study – Birth Cohort, a nationally representative U.S. cohort of births in 2001. Pregnancy weight gain was standardized into gestational age- and prepregnancy body mass index (BMI)-specific z-scores. Excess postpartum weight increase was defined as ≥10 kg increase from prepregnancy weight. We defined child overweight/obesity as BMI ≥ 85th percentile, and low reading and math achievement as scores one standard deviation below the mean. We used survey-weighted multivariable modified Poisson models with a log link to relate gestational weight gain z-score with each outcome.

Results: Excess postpartum weight increase occurred in 40% of mothers. Approximately 28% of twins were affected by overweight/obesity, and 16% and 14% had low reading and low math scores. There was a positive linear relationship between pregnancy weight gain and both excess

*Correspondence: Lisa M. Bodnar, PhD, Department of Epidemiology, University of Pittsburgh, 5128 Public Health, 130 DeSoto St, Pittsburgh, PA 15261, bodnar@edc.pitt.edu, 412-624-9032 (voice).

postpartum weight increase and childhood overweight/obesity. Compared with a gestational weight gain z-score 0 SD (equivalent to 20 kg at 37 weeks gestation), a weight gain z-score of +1 SD (27 kg) was associated with 6.3 (0.71, 12) cases of excess weight increase per 1000 women and 4.5 (0.81, 8.2) excess cases of child overweight/obesity per 100 twins. Gestational weight gain was not related to kindergarten academic readiness.

Conclusions: The high prevalence of excess postpartum weight increase and childhood overweight/obesity within the recommended ranges of gestational weight gain for twin pregnancies suggests that these guidelines could be inadvertently contributing to longer-term maternal and child obesity.

Introduction

Weight gain during pregnancy has important consequences for maternal and child health. High pregnancy weight gain is a strong determinant of excess maternal postpartum weight retention, which in turn, increases a woman's risk of subsequent obesity [1, 2]. Women who retain postpartum weight are also more likely to begin their next pregnancies at a higher body mass index, which increases the likelihood of many adverse pregnancy outcomes [3]. Children born to mothers who gain too much weight during pregnancy are also at increased risk of obesity in childhood, adolescence, and adulthood [4, 5].

In 2009, the Institute of Medicine (IOM) developed weight gain guidelines for singleton pregnancies based on robust literature linking weight gain to adverse health outcomes, including longer-term outcomes such as maternal and child obesity. However, the IOM could only publish provisional guidelines for twin pregnancies[6]. The provisional twin guidelines were established without data regarding the consequences of pregnancy weight gain on longer-term health outcomes. Understanding optimal pregnancy weight gain for twin gestations is important because women pregnant with twins gain more weight than women with singleton pregnancies and are also more likely to have adverse pregnancy outcomes [6]. Despite calls from the IOM for research in this area [6], major knowledge gaps remain, especially on relations between pregnancy weight gain and longer-term health outcomes for mothers and children. We sought to evaluate the association between maternal weight gain in twin pregnancies and the risk of maternal postpartum weight increase, childhood obesity, and child cognitive ability at 5 years.

Methods

We used data from the Early Childhood Longitudinal Study – Birth (ECLS-B) Cohort, a nationally representative cohort of U.S. children born in 2001, sampled from birth certificates and followed to kindergarten entry [7]. Parents were contacted at 9 months and, after providing informed, written consent, were interviewed at baseline. Families participated in follow-up study visits at 2, 4, and 5 years. Children who delayed entry to kindergarten or repeated kindergarten were contacted again at 6 years. A total of 10,700 infants were enrolled, including an oversampling of twins (1650 twins born to 850 mothers). Numbers of participants are rounded to the nearest 50, as required by the U.S. Department of Education. Twins and their mothers were not eligible for the kindergarten assessment if they died, moved out of the country, or did not participate in any data collection since the 9-

month study visit (12%) or if they were not selected to participate in the kindergarten assessment due to budget constraints (8%). An additional 9% were lost to follow-up. Of the 1200 twins and 600 mothers who participated in the kindergarten wave, 200 twins and 100 mothers were excluded because of missing data on gestational weight gain, the outcomes of interest, or confounders. The final analytic sample was 1000 twins and 450 mothers (83% of the those who completed the kindergarten assessment). We used ECLS-B sampling weights to maintain a sample with characteristics representative of births in 2001 and to account for differential selection probabilities and differential patterns of response/nonresponse. We used the WKR0 sampling weight, which is used to conduct analyses with kindergarten child assessment data alone or in conjunction with parent data [8, 9]. When weighted, our analytic samples represented ~44,930 mothers of twins and ~98,770 twin children born in 2001 in the United States. The University of Pittsburgh institutional review board determined this project to be exempt from ongoing review.

At enrollment, mothers self-reported their prepregnancy weight and height. We calculated body mass index (BMI) as weight (kg) / height $(m)^2$ and categorized it as underweight, normal weight, overweight, or obese. Total gestational weight gain was ascertained from birth certificates in 83% of participants and filled in with maternal self-report at enrollment for the remaining. We calculated prepregnancy BMI- and gestational age-standardized z-scores using twin-specific charts [10]. We categorized gestational weight gain as <−1, −1 to < 0, 0 to +1, > +1 standard deviations (SD), which corresponds to ≤14, 14–20, 20–27 and ≥27 kg total weight gain at 37 weeks among normal weight women with twin pregnancies, to 5.5 kg, 11 kg, 18 kg, 28 kg, and 41 kg in overweight women with twin pregnancies, and to 0.9 kg, 6.4 kg, 14 kg, 26 kg, and 43 kg in women with obesity with twin pregnancies. To evaluate whether absolute weight gain is associated with the outcomes of interest, we performed a sensitivity analyses using total weight gain (kg).

Mothers self-reported their current weight at the 5-year study visit. There is no gold standard definition for excess postpartum weight increase. We defined excess postpartum weight increase at 5 years as ≥10 kg change from prepregnancy weight, a cut-point the 2009 IOM committee evaluated in their report [6]. We refer to this as ‘postpartum weight increase’, as weight change could be due to either postpartum weight retention or postpartum weight gain. We performed a sensitivity analysis defining excess weight increase as a BMI change ≥5 kg/m^2.

Children were weighed and their height measured using a standardized protocol at the 5- or 6-year visit [7]. We calculated age- and sex-specific BMI z-scores and percentiles [11], and defined child overweight/obesity as BMI ≥ 85th percentile. In sensitivity analyses, we also evaluated child obesity (BMI ≥ 95th percentile).

Cognitive ability at kindergarten entry was measured by trained interviewers conducting direct assessments of children’s reading and math ability at the age 5- or 6-year visit [7]. Children’s language and emergent literacy skills were evaluated in a direct reading assessment, and their knowledge of number sense, operations, measurement, patterns, and geometry were evaluated in a direct math assessment. The ECLS-B study team created composite reading and math scores, and we standardized these scores based on the full study cohort. We defined low scores as scores that were at least one standard deviation below the sample mean.

Information on maternal age, education, and parity were collected from the birth certificate. At enrollment, parents reported maternal race/ethnicity, smoking in the last 3 months of pregnancy, marital status, family socioeconomic status [12], food security of the family (secure, insecure without hunger, and insecure with hunger), and use of assistive reproductive technology. Twin zygosity (identical or fraternal) information was collected at the 2-year parent interview.

Statistical analysis

All analyses were conducted in StataMP 14. We estimated the association between gestational weight gain z-score and each binary maternal and child outcome using multivariable modified Poisson models with a log link, and linear regression for child BMI z-score. We used the *svy, subpop( )* command to weight all models.. We used a “twins-as-individuals” modeling approach because we were not interested in studying the twin pair itself [13]. To accommodate flexible, nonlinear relations, we modeled gestational weight gain z-score as a restricted cubic spline with three knots set at the default locations [14]. Confounders were identified *a priori* using theory-based causal graphs [15]. All models were adjusted for child age at kindergarten assessment, child sex, zygosity, maternal age, parity, race/ethnicity, smoking in the last 3 months of pregnancy, use of assisted reproductive technologies, height, prepregnancy BMI, household socioeconomic status level, and food security.

After model estimation, we calculated adjusted predicted probabilities and risk differences (RD) with 95% confidence intervals (CI) via marginal standardization at selected values from −2 SD to +2 SD (approximately 5th to 97th percentiles of weight gain z-scores observed in our cohort) compared with a z-score 0 SD. We also evaluated the difference in risk within the IOM provisional weight gain guidelines for twins, which correspond to z-scores of approximately −0.5 to +0.5 SD: 17–25 kg at 37 weeks’ gestation for normal weight women, 14–23 kg at 37 weeks’ gestation for overweight women, and 11–19 kg at 37 week’s gestation for women with obesity. We plotted the average adjusted risks and 95% CI for each outcome. We multiplied the risk differences by 100 to estimate the number of excess (or prevented) cases per 100.

We performed several sensitivity analyses. We explored effect modification on the additive scale by maternal prepregnancy BMI (BMI <25 kg/m^2 vs. ≥25 kg/m^2) by visually inspecting the stratified risk curves. We performed sensitivity analyses using total absolute gestational weight gain (kg). Additionally, we imputed missing data using the multivariate normal imputation model, which uses an iterative Markov Chain Monte Carlo method [16, 17]. Data were imputed at the child level, but the pregnancy identifier was included in the imputation model to inform the estimates.

Code availability—Computer code and data will not be available due to data use agreements with the U.S. Department of Education.

Results

A majority of mothers were 30–35 years old, non-Hispanic White, college graduates, multiparous, non-smokers, and married (Table 1). Approximately 41% were affected by prepregnancy overweight or obesity. Almost one-quarter of women used an assisted reproductive technology to conceive, and approximately half of women had an income below 185% of the federal poverty line. Twins were born at a mean (±SE) 36 (±0.12) weeks gestation and 2429 (±22) g birthweight. The mean (±SE) absolute pregnancy weight gain was 17 (±0.41) kg and pregnancy weight gain z-score was −0.21 (±0.060).

Postpartum weight increase

The mean (SE) postpartum weight increase at 5 years was 9.2 (±0.57) kg, 59% of mothers had a 5-kg or more increase, and 40% of mothers had a 10-kg or more increase. Weight increase and prevalence of excess weight increase were lowest among women with a gestational weight gain z-score <−1 SD (≤14 kg at 37 weeks for a normal weight woman) and highest among women with a gestational weight gain z-score >+1 SD (equivalent to >27 kg) (Table 2).

After adjusting for child age, child sex, zygosity, maternal age, parity, race/ethnicity, smoking, use of assisted reproductive technologies, height, prepregnancy BMI, household socioeconomic status, and food security, the prevalence of excess postpartum weight increase rose steadily from weight gain z-scores of −2 SD to +2 SD (Figure 1, Panel A). Compared with a gestational weight gain z-score 0 SD (equivalent to 20 kg at 37 weeks gestation in a normal weight woman with a twin pregnancy), weight gain z-scores of +0.5 SD (23 kg at 37 weeks gestation in a normal weight woman with a twin pregnancy) and +1 SD (27 kg at 37 weeks gestation in a normal weight woman with a twin pregnancy) were associated with 3.2 (95% CI 0.86, 5.5) and 6.3 (0.71, 12) excess cases of postpartum weight increase per 100 women, respectively.

The absolute risk of excess postpartum weight increase was high, even within the provisional range the IOM recommended for twin pregnancies, which correspond to weight gain z-scores of approximately −0.5 to +0.5 SD. The prevalence was 38% (95% CI 32%, 44%) at the lower limit of the IOM-recommended range and 45% (37%, 52%) at the upper limits. The lower limit of the current twin weight gain recommendations was associated with 6.6 (95% CI 2.2, 11) fewer cases of excess postpartum weight increase per 100 women than weight gain at the upper limit.

When we defined excess postpartum weight increase as a ≥5-kg/m^2 increase in BMI, results were similar (Appendix Figure 1).

Childhood overweight

At kindergarten entry, the mean (±SE) child BMI was 16 (±0.080) kg/m^2 and the mean (±SE) BMI z-score was 0.41 (±0.040). Approximately 28% of twins were affected by overweight/obesity and 12% affected by obesity. Child BMI z-score and prevalence of overweight/obesity increased with maternal gestational weight gain (Table 2). There was a positive, linear relation between pregnancy weight gain z-score and childhood overweight/

obesity (Figure 1, Panel B). After confounder adjustment, women with gestational weight gain z-scores of +0.5 (23 kg) and +1 (27 kg) had 2.2 (0.69, 3.7) and 4.5 (0.81, 8,2) excess cases of childhood overweight/obesity compared with women who had z-scores of 0 (all z-scores represent 37-week gain in a normal weight woman) (Table 3). There were 4.2 (1.2, 7.3) excess cases of childhood overweight/obesity comparing the upper to the lower limit of current win pregnancy weight gain recommendations (adjusted prevalence 30% (25%, 36%) vs. 26% (22%, 30%)).

The same positive association was observed for childhood BMI z-score (Appendix Figure 2).

Child reading and math achievement

The early reading and math achievement measures in twins had mean (±SE) z-scores of 0.08 (±0.050) and 0.03 (±0.040), respectively, and 16% and 14% of twins had low reading and math scores. There were no meaningful differences in the prevalence of low achievement in either domain according to pregnancy weight gain z-score category (Table 2). Additionally, the null association remained after confounder adjustment in the spline modeling (Figure 1, Panels C and D; Table 3).

Maternal prepregnancy overweight did not modify the relations between gestational weight gain z-score and any of the 4 outcomes (Appendix Figure 3). There were no important differences in the relations when z-scores were replaced with absolute gestational weight gain (kg) (Appendix Figure 4). When we reran our analyses after multiple imputation, we found no meaningful differences (Appendix Table 1, Appendix Table 2).

Discussion

In this nationally representative U.S. cohort, excess postpartum weight increase and childhood obesity increased with higher pregnancy weight gain in a linear manner. The IOM-recommended pregnancy weight gain range was associated with high rates of excess postpartum weight increase, affecting 37% and 44% of women at the lower and upper limits, respectively. The same was true for childhood overweight/obesity, with 30% and 26% of twins affected at the upper and lower limits of weight gain recommendations. Pregnancy weight gain was not related to child academic readiness at kindergarten. These associations did not vary by prepregnancy overweight.

We are unaware of other studies relating maternal weight gain in twin pregnancies to postpartum weight. However, our results are consistent with studies in singleton pregnancies. Two meta-analyses of randomized trials in singleton gestations have shown that diet and/or physical activity interventions for preventing excessive weight gain during pregnancy reduce postpartum weight retention at 6–12 months [18, 19]. Similarly, a meta-analysis of observational studies reported that excessive gestational weight gain in singletons was associated with higher mean postpartum weight retention at 3 and ≥15 years postpartum [20]. Other research has linked pregnancy weight gain with postpartum adiposity at 7–8 years [21, 22] as well as adverse cardiometabolic markers from 3 to 16 years postpartum [23-25].

To our knowledge, there are no studies of child weight in relation to maternal weight gain in twin gestations. Using singleton pregnancies from the same ECLS-B cohort as our work, researchers observed that high gestational weight gain (z-score of approximately +1 SD) was associated with increasing child BMI z-score [26]. They found no BMI increase within the IOM-recommended weight gain range. Two meta-analyses have linked excessive pregnancy weight gain to child overweight/obesity (odds ratios approximately 1.4) in childhood, adolescence, and adulthood [4, 5]. For comparison, the adjusted prevalence ratio (95% CI) that we observed with weight gain z-score >+1 compared with 0 was 1.2 (1.0, 1.3). Excessive pregnancy weight gain has also been positively associated with child fat mass and cardiometabolic traits [27-29]. The consistency of data linking high pregnancy weight gain in singletons to maternal and child obesity support the validity of our study estimates in twins. Our results can be used to inform the creation of evidence-based weight gain guidelines for mothers of twins that take excess postpartum weight increase and childhood overweight/obesity into account.

We found no association between pregnancy weight gain and twin academic ability at kindergarten. Although we are unaware of similar studies in twins, the literature on singletons is equivocal. Excessive pregnancy weight gain was associated with lower reading and spelling scores at 6, 10, and 14 years in one cohort [30], while in another, inadequate weight gain was related to low academic ability at 4 and 16 years [31]. Three other studies of 3- to 10-year-old children found no association between gestational weight gain and child cognitive ability [32-35], including one study of 31,968 children that used a sibling comparison design to account for unmeasured familial factors [32]. The 2009 IOM Committee called for research in this area out of concern that child neurocognitive development may be impaired by maternal fasting if ketone bodies are used as metabolic fuel for the fetal brain [36-39]. Our sample had too few women with very low weight gain to adequately address this question, but thus far, research does not support this concern.

The ECLS-B did not collect data between the index pregnancy and the 5-year study visit on maternal weight or subsequent pregnancies. This information would have permitted an understanding of whether the excess weight at 5 years was retained from the twin pregnancy, retained from a subsequent pregnancy, or gained in the postpartum period. Some evidence suggests that excessive pregnancy weight gain in a singleton pregnancy remains associated with obesity at age 40, even when accounting for intervening pregnancies [2]. The ECLS-B also did not ask women at the 5 year visit whether they were currently pregnant. It is therefore possible that postpartum weight was misclassified for a small proportion of mothers.

Mothers self-reported their weight before conception of the twin pregnancy and the 5-year study visit. Evidence suggests that, on average, weight is over- or under-reported to a small degree [40], and that reporting accuracy varies according to maternal characteristics in singletons [41] and twins [42]. An internal validation study would be needed to evaluate the direction and magnitude of this potential misclassification bias [43]. However, our previous work [44-46] suggests that this is unlikely to be an important concern. Our sample was relatively small, which may have limited our ability to detect moderate effects and to evaluate effect measure modification by prepregnancy BMI. Although attrition in the study sample raises the potential for selection bias, the sample weights we used account for differential loss-to-follow up, thereby lessening this concern. Our study was observational, and therefore we cannot draw causal inference from our findings. We assumed that conditioning on baseline covariates in our analysis accounted for systematic differences among women with varying weight gains, but we cannot rule out the potential for unmeasured confounding. ECLS-B is nationally representative of births in 2001. While the cohort was enrolled 20 years ago, obesity and excessive weight gain remain relevant problems today.

Current provisional guidelines for twin pregnancies were created in the absence of information on longer-term health outcomes such as obesity. Our study found concerningly high rates of excess postpartum weight increase and childhood overweight/obesity within the current IOM-recommended ranges, suggesting that recommendations could be inadvertently contributing to longer-term maternal and child obesity and its sequelae. There is an urgent need to develop new guidelines that consider obesity risk against risks of infant death, preterm birth, and small-for-gestational-age birth, which increase with lower weight gain in twins [46]. Taken together, these data highlight the importance of pregnancy weight gain guidelines for mothers with twin gestations that balance the complex trade-off between low and high weight gain for maternal and child health.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Competing Interests: This study is supported by grant funding from the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development (NICHD) R01 HD094777 to Drs. Bodnar and Hutcheon. Dr. Hutcheon holds a Canada Research Chair in Perinatal Population Health from the Canadian Federal Government. The funders had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript. The authors declare no other competing interests.

References

1. Perez-Escamilla R, Kac G. Childhood obesity prevention: a life-course framework. Int J Obes Suppl 2013; 3(Suppl 1): S3–S5. [PubMed: 25018875]
2. Abrams B, Coyle J, Cohen AK, Headen I, Hubbard A, Ritchie L et al. Excessive Gestational Weight Gain and Subsequent Maternal Obesity at Age 40: A Hypothetical Intervention. Am J Public Health 2017; 107(9): 1463–1469. [PubMed: 28727522]
3. Poston L, Harthoorn LF, Van Der Beek EM. Obesity in pregnancy: implications for the mother and lifelong health of the child. A consensus statement. Pediatr Res 2011; 69(2): 175–80. [PubMed: 21076366]
4. Mamun AA, Mannan M, Doi SA. Gestational weight gain in relation to offspring obesity over the life course: a systematic review and bias-adjusted meta-analysis. Obes Rev 2014; 15(4): 338–47. [PubMed: 24321007]
5. Voerman E, Santos S, Patro Golab B, Amiano P, Ballester F, Barros H et al. Maternal body mass index, gestational weight gain, and the risk of overweight and obesity across childhood: An individual participant data meta-analysis. PLoS Med 2019; 16(2): e1002744. [PubMed: 30742624]
6. Institute of Medicine. Weight Gain During Pregnancy: Reexamining the Guidelines, National Academies Press: Washington, DC, 2009.

7. Najarian M, Snow K, Lennon J, Kinsey S. Early Childhood Longitudinal Study, Birth Cohort (ECLS-B), Preschool-Kindergarten 2007 Psychometric Report (NCES 2010-009), National Center for Education Statistics, Institute of Education Sciences, US Department of Education: Washington, DC, 2010.

8. Snow K, Thalji L, Derecho A, Wheeless JL, Lennon J, Kinsey S et al. User's Manual for the ECLS-B Longitudinal 9-Month - Preschool Restricted Use Data File and Electronic Codebook, National Center for Education Statistics, Institute of Education Sciences, US Department of Education: Washington, D.C., 2007.

9. Snow K, Thalji L, Derecho A, Wheeless JL, Lennon J, Kinsey S et al. Early Childhood Longitudinal Study, Birth Cohort (ECLS-B) Kindergarten 2006 and 2007 Data File User's Manual, National Center for Education Statistics, Institute of Education Sciences, US Department of Education: Washington, D.C., 2009.

10. Hutcheon JA, Platt RW, Abrams B, Braxter BJ, Eckhardt CL, Himes KP et al. Pregnancy Weight Gain by Gestational Age in Women with Uncomplicated Dichorionic Twin Pregnancies. Paediatr Perinat Epidemiol 2018.

11. Grummer-Strawn LM, Reinold C, Krebs NF. Use of World Health Organization and CDC growth charts for children aged 0-59 months in the United States. MMWR Recomm Rep 2010; 59(RR-9): 1–15.

12. Office of the Assistant Secretary for Planning and Evaluation in the US Department of Health & Human Services. The 2011 HHS Poverty Guidelines. In, 2011.

13. Carlin JB, Gurrin LC, Sterne JA, Morley R, Dwyer T. Regression models for twin studies: a critical review. Int J Epidemiol 2005; 34(5): 1089–99. [PubMed: 16087687]

14. Harrell FE Jr., Lee KL, Pollock BG. Regression models in clinical studies: determining relationships between predictors and response. J Natl Cancer Inst 1988; 80(15): 1198–202. [PubMed: 3047407]

15. Glymour MM, Greenland S. Causal diagrams. In: Rothman KJ, Greenland S, Lash TL (eds). Modern Epidemiology, 3rd *edition*. Lippincott Williams & Wilkins: Philadelphia, PA, 2008.

16. Royston P Multiple imputation of missing values: Further update of ice, with an emphasis on categorical variables. Stata J 2009; 9(3): 466–477.

17. Sterne JA, White IR, Carlin JB, Spratt M, Royston P, Kenward MG et al. Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls. BMJ 2009; 338: b2393. [PubMed: 19564179]

18. Michel S, Raab R, Drabsch T, Gunther J, Stecher L, Hauner H. Do lifestyle interventions during pregnancy have the potential to reduce long-term postpartum weight retention? A systematic review and meta-analysis. Obes Rev 2019; 20(4): 527–542. [PubMed: 30548769]

19. Tanentsapf I, Heitmann BL, Adegboye AR. Systematic review of clinical trials on dietary interventions to prevent excessive weight gain during pregnancy among normal weight, overweight and obese women. BMC Pregnancy and Childbirth 2011; 11: 81. [PubMed: 22029725]

20. Nehring I, Schmoll S, Beyerlein A, Hauner H, von Kries R. Gestational weight gain and long-term postpartum weight retention: a meta-analysis. Am J Clin Nutr 2011; 94(5): 1225–31. [PubMed: 21918221]

21. Widen EM, Whyatt RM, Hoepner LA, Ramirez-Carvey J, Oberfield SE, Hassoun A et al. Excessive gestational weight gain is associated with long-term body fat and weight retention at 7 y postpartum in African American and Dominican mothers with underweight, normal, and overweight prepregnancy BMI. Am J Clin Nutr 2015; 102(6): 1460–7. [PubMed: 26490495]

22. 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. Am J Clin Nutr 2013; 98(5): 1218–25. [PubMed: 24047920]

23. Soria-Contreras DC, Rifas-Shiman SL, Aris IM, Perng W, Switkowski KM, Tellez-Rojo MM et al. Weight Trajectories After Delivery are Associated with Adiposity and Cardiometabolic Markers at 3 Years Postpartum Among Women in Project Viva. J Nutr 2020.

24. Walter JR, Perng W, Kleinman KP, Rifas-Shiman SL, Rich-Edwards JW, Oken E. Associations of trimester-specific gestational weight gain with maternal adiposity and systolic blood pressure at 3 and 7 years postpartum. Am J Obstet Gynecol 2015; 212(4): 499 e1–12. [PubMed: 25446696]

25. Fraser A, Tilling K, Macdonald-Wallis C, Hughes R, Sattar N, Nelson SM 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; 93(6): 1285–92. [PubMed: 21471282]
26. Hinkle SN, Sharma AJ, Swan DW, Schieve LA, Ramakrishnan U, Stein AD. Excess gestational weight gain is associated with child adiposity among mothers with normal and overweight prepregnancy weight status. J Nutr 2012; 142(10): 1851–8. [PubMed: 22955516]
27. Karachaliou M, Georgiou V, Roumeliotaki T, Chalkiadaki G, Daraki V, Koinaki S et al. Association of trimester-specific gestational weight gain with fetal growth, offspring obesity, and cardiometabolic traits in early childhood. Am J Obstet Gynecol 2015; 212(4): 502 e1–14. [PubMed: 25557209]
28. Lu W, Zhang X, Wu J, Mao X, Shen X, Chen Q et al. Association between trimester-specific gestational weight gain and childhood obesity at 5 years of age: results from Shanghai obesity cohort. BMC Pediatr 2019; 19(1): 139. [PubMed: 31046723]
29. Hivert MF, Rifas-Shiman SL, Gillman MW, Oken E. Greater early and mid-pregnancy gestational weight gains are associated with excess adiposity in mid-childhood. Obesity (Silver Spring) 2016; 24(7): 1546–53. [PubMed: 27345963]
30. Pugh SJ, Hutcheon JA, Richardson GA, Brooks MM, Himes KP, Day NL et al. Child academic achievement in association with pre-pregnancy obesity and gestational weight gain. J Epidemiol Community Health 2016; 70(6): 534–40. [PubMed: 26729706]
31. Gage SH, Lawlor DA, Tilling K, Fraser A. Associations of Maternal Weight Gain in Pregnancy With Offspring Cognition in Childhood and Adolescence: Findings From the Avon Longitudinal Study of Parents and Children. American journal of epidemiology 2013.
32. Keim SA, Pruitt NT. Gestational weight gain and child cognitive development. International Journal of Epidemiology 2012; 41(2): 414–22. [PubMed: 22314966]
33. Hinkle SN, Albert PS, Sjaarda LA, Grewal J, Grantz KL. Trajectories of maternal gestational weight gain and child cognition assessed at 5 years of age in a prospective cohort study. J Epidemiol Community Health 2016; 70(7): 696–703. [PubMed: 26759126]
34. Pugh SJ, Richardson GA, Hutcheon JA, Himes KP, Brooks MM, Day NL et al. Maternal Obesity and Excessive Gestational Weight Gain Are Associated with Components of Child Cognition. J Nutr 2015; 145(11): 2562–9. [PubMed: 26423736]
35. Kominiarek MA, Smid MC, Mele L, Casey BM, Sorokin Y, Reddy UM et al. Child Neurodevelopmental Outcomes by Prepregnancy Body Mass Index and Gestational Weight Gain. Obstet Gynecol 2018; 132(6): 1386–1393. [PubMed: 30399108]
36. Shambaugh GE 3rd, Angulo MC, Koehler RR. Fetal fuels. VII. Ketone bodies inhibit synthesis of purines in fetal rat brain. Am J Physiol 1984; 247(1 Pt 1): E111–7. [PubMed: 6742185]
37. Mendola P, Selevan SG, Gutter S, Rice D. Environmental factors associated with a spectrum of neurodevelopmental deficits. Ment Retard Dev Disabil Res Rev 2002; 8(3): 188–97. [PubMed: 12216063]
38. Felig P. Maternal and fetal fuel homeostasis in human pregnancy. Am J Clin Nutr 1973; 26(9): 998–1005. [PubMed: 4600999]
39. Gin H, Vambergue A, Vasseur C, Rigalleau V, Dufour P, Roques A et al. Blood ketone monitoring: a comparison between gestational diabetes and non-diabetic pregnant women. Diabetes Metab 2006; 32(6): 592–7. [PubMed: 17296512]
40. Headen I, Cohen AK, Mujahid M, Abrams B. The accuracy of self-reported pregnancy-related weight: a systematic review. Obes Rev 2017; 18(3): 350–369. [PubMed: 28170169]
41. Bodnar LM, Abrams B, Bertolet M, Gernand AD, Parisi SM, Himes KP et al. Validity of birth certificate-derived maternal weight data. Paediatric and Perinatal Epidemiology 2014; 28(3): 203–12. [PubMed: 24673550]
42. Bodnar LM, Abrams B, Siminerio L, Lash TL. Validity of birth certificate-derived maternal weight data in twin pregnancies. Matern Child Nutr 2016; 12(3): 632–8. [PubMed: 25522306]
43. Lash TL. Heuristic thinking and inference from observational epidemiology. Epidemiology 2007; 18(1): 67–72. [PubMed: 17149141]

44. Bodnar LM, Pugh SJ, Lash TL, Hutcheon JA, Himes KP, Parisi SM et al. Low gestational weight gain and risk of adverse perinatal outcomes in obese and severely obese women. Epidemiology 2016; 27(6): 894–902. [PubMed: 27682365]

45. Bodnar LM, Siminerio LL, Himes KP, Hutcheon JA, Lash TL, Parisi SM et al. Maternal obesity and gestational weight gain are risk factors for infant death. Obesity (Silver Spring) 2015; 24(2): 490–8. [PubMed: 26572932]

46. Bodnar LM, Himes KP, Abrams B, Lash TL, Parisi SM, Eckhardt CL et al. Gestational Weight Gain and Adverse Birth Outcomes in Twin Pregnancies. Obstet Gynecol 2019; 134(5): 1075–1086. [PubMed: 31599828]

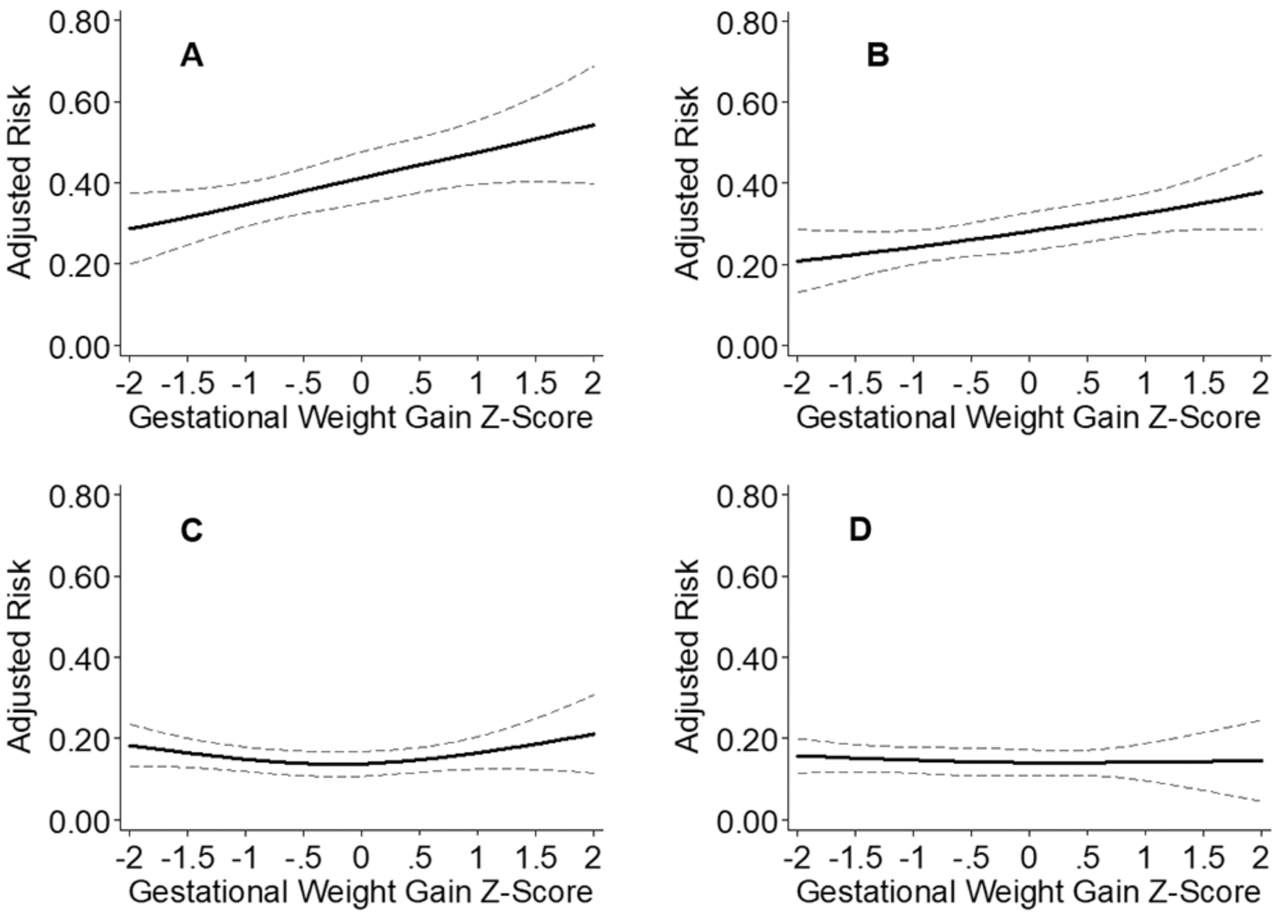

Figure 1.

Adjusted associations between gestational weight gain z-score and maternal and child health outcomes: maternal excess postpartum weight increase at 5 years (Panel A), childhood overweight/obesity at kindergarten entry (Panel B), low kindergarten reaching achievement (Panel C), and low kindergarten math achievement (Panel D), n = 450 mothers and n = 1000 twins, Early Childhood Longitudinal Study Birth Cohort, United States, 2001-2007.

The solid lines represent the point estimate and dashed lines represent its 95% confidence bands. Gestational weight gain z-scores of −2, −1, 0, +1, and +2 standard deviations are equivalent to total maternal weight gain at 37 weeks gestation of 9.4 kg, 14 kg, 20 kg, 27 kg, and 37 kg, respectively, in normal weight women, 5.5 kg, 11 kg, 18 kg, 28 kg, and 41 kg in overweight women, and 0.9 kg, 6.4 kg, 14 kg, 26 kg, and 43 kg in women with obesity. Gestational weight gain z-score was modeled as a restricted cubic spline with 3 knots. Predicted risks were marginally standardized set at the population average in the presence of adjustment for child age, child sex, zygosity, maternal age, parity, race/ethnicity, smoking in the last 3 months of pregnancy, use of assisted reproductive technologies, height, and prepregnancy BMI, household socioeconomic status level, and food security. Sample sizes were rounded to the nearest 50, per U.S. Department of Education requirements.

Table 1.

Characteristics of mothers and their twins, the Early Childhood Longitudinal Study Birth Cohort (United States, 2001–2007).[1]

	Weighted % or mean (SE)
Maternal Characteristics (n = 450)	
Age at delivery, years	29 (0.31)
Age at delivery, years	
<25	24
25-29	27
30-35	36
>35	13
Race/ethnicity	
Non-Hispanic White	65
Non-Hispanic Black	15
Hispanic	9.1
Other	11
Prepregnancy body mass index, kg/m^2	25 (0.26)
Prepregnancy body mass index[3]	
Underweight	3.2
Normal weight	56
Overweight	22
Obese	19
Education at delivery	
Less than high school	15
High school or equivalent	27
Some college	24
College graduate	33
Primiparous	
Yes	36
No	64
Smoked during last 3 months of pregnancy	
Yes	9.3
No	91
Marital status at delivery	
Married	75
Unmarried	25
Use of assistive reproductive technology	
Yes	24
No	76
Family socioeconomic status at delivery[2]	
At or above 185% of federal poverty level	54

	Weighted % or mean (SE)
Below 185% of federal poverty	46
Gestational weight gain, kg	17 (0.41)
Gestational weight gain z-score	−0.21 (0.060)
Gestational weight gain z-score category[4]	
<−1	21
−1 to < 0	35
0 to + 1	32
>+1	12
Twin Characteristics (n = 1000)	
Sex	
Female	50
Male	50
Birth weight, g	2429 (22)
Gestational age at birth, weeks	36 (0.12)
Preterm birth < 34 weeks	
Yes	15
No	85
Twin zygosity	
Monozygotic	22
Dizygotic	78
Age at kindergarten follow-up, months	65 (0.15)

SE, standard error

[1] Percentages and means (SEs) are weighted for the complex survey design, and sample sizes are rounded to the nearest 50, per U.S. Department of Education requirements.

[2] Federal poverty levels are determined by the U.S. Department of Health and Human Services every year according to household size and income. A cut-point of 185% poverty is used to determine eligibility for government programs, including the Special Supplemental Program for Women, Infants, and Children

[3] Underweight (<18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), overweight (25–29.9 kg/m^2), grade obese (≥30 kg/m^2).

[4] Gestational weight gain z-scores of −1, 0, and +1 standard deviations are equivalent to total maternal weight gain at 37 weeks gestation of 14 kg, 20 kg, and 27 kg, respectively, in normal weight women, 11 kg, 18 kg, and 28 kg in overweight women, and 6.4 kg, 14 kg, and 26 kg in women with obesity.

Table 2.

Unadjusted associations between gestational weight gain and maternal weight increase at 5 years postpartum, childhood overweight/obesity at kindergarten entry, low kindergarten reaching achievement, and low kindergarten math achievement, n = 450 mothers and n = 1000 twins, Early Childhood Longitudinal Study Birth Cohort, United States, 2001-2007. [1]

Gestational weight gain z-score[2]	Postpartum weight increase, kg, mean (SE)	Excess postpartum weight increase[3], %	Child BMI z-score, mean (SE)	Childhood overweight / obesity[4], %	Reading z-score, mean (SE)	Low reading score[5], %	Math z-score, mean (SE)	Low math score[5], %
<−1	7.5 (0.91)	34	0.19 (0.084)	21	−0.015 (0.086)	19	−0.090 (0.092)	18
−1 to <0	7.9 (0.71)	36	0.34 (0.082)	26	0.081 (0.065)	12	0.026 (0.050)	14
0 to +1	10 (0.91)	43	0.53 (0.067)	30	0.16 (0.075)	15	0.11 (0.069)	14
>+1	13 (1.9)	56	0.68 (0.053)	40	0.030 (0.072)	19	0.010 (0.080)	12

BMI: Body Mass Index; SE: standard error.

[1] Percentages and means (SEs) were weighted for the complex survey design, and sample sizes are rounded to the nearest 50, per U.S. Department of Education requirements.

[2] Gestational weight gain z-scores of −1, 0, and +1 standard deviations are equivalent to total maternal weight gain at 37 weeks gestation of 14 kg, 20 kg, and 27 kg, respectively, in normal weight women, 11 kg, 18 kg, and 28 kg in overweight women, and 6.4 kg, 14 kg, and 26 kg in women with obesity.

[3] Defined as ≥10 kg above prepregnancy weight at 5 years postpartum.

[4] Age- and sex-specific BMI ≥ 85th percentile.

[5] Below one standard deviation of the mean in the entire cohort.

Table 3.

Adjusted associations between gestational weight gain and maternal weight increase at 5 years postpartum, childhood overweight/obesity at kindergarten entry, low kindergarten reaching achievement, and low kindergarten math achievement, n = 450 mothers and n = 1000 twins, Early Childhood Longitudinal Study Birth Cohort, United States, 2001-2007.[1]

	Excess postpartum weight increase[3]	Childhood overweight/obesity[5]	Childhood BMI z-score	Low Reading Score[6]	Low Math Score[6]
Gestational weight gain z-score[2]	**Adjusted[4] number of excess cases per 100 pregnancies (95% CI)**	**Adjusted[4] number of excess cases per 100 pregnancies (95% CI)**	**Adjusted[4] mean difference (95% CI)**	**Adjusted[4] number of excess cases per 100 pregnancies (95% CI)**	**Adjusted[4] number of excess cases per 100 pregnancies (95% CI)**
−2	−13 (−24, −1.2)	−7.3 (−18, 2.9)	−0.13 (−0.38, 0.12)	4.8 (−1.1, 11)	1.8 (−3.3, 6.9)
−1	−6.7 (−12, −0.92)	−3.9 (−8.8, 0.93)	−0.076 (−0.18, 0.023)	1.4 (−0.59, 3.3)	0.69 (−1.2, 2.6)
−0.5	−3.4 (−6.0, −0.77)	−2.0 (−4.1, 0.056)	−0.043 (−0.084, −0.0034)	0.28 (−0.54, 1.1)	0.26 (−0.71, 1.2)
0	Ref	Ref	Ref	Ref	Ref
+0.5	3.2 (0.86, 5.5)	2.2 (0.69, 3.7)	0.059 (0.013, 0.11)	0.91 (−0.36, 2.2)	−0.010 (−2.0, 1.9)
+1	6.3 (0.71, 12)	4.5 (0.81, 8.2)	0.13 (0.016, 0.24)	2.6 (−0.73, 6.0)	0.13 (−4.5, 4.8)
+2	13 (−1.4, 28)	9.7 (−0.38, 20)	0.27 (0.012, 0.52)	7.3 (−2.6, 17)	0.48 (−10, 11)

CI, confidence interval.

1. Models are weighted to account for the complex survey design, and sample sizes are rounded to the nearest 50, per U.S. Department of Education requirements.

2. Gestational weight gain z-scores of −2, −1, 0, +1, and +2 standard deviations are equivalent to total maternal weight gain at 37 weeks in a twin gestation of 9.4 kg, 14 kg, 20 kg, 27 kg, and 37 kg, respectively, in normal weight women, 5.5 kg, 11 kg, 18 kg, 28 kg, and 41 kg in overweight women, and 0.9 kg, 6.4 kg, 14 kg, 26 kg, and 43 kg in women with obesity.

3. Defined as ≥10 kg above prepregnancy weight at 5 years postpartum.

4. All models were adjusted for child age, child sex, zygosity, maternal age, parity, race/ethnicity, smoking in the last 3 months of pregnancy, use of assisted reproductive technologies, height, and prepregnancy BMI, household socioeconomic status level, and food security.

5. Age- and sex-specific BMI ≥ 85^{th} percentile.

6. Below one standard deviation of the mean in the entire cohort.