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Maternal Gestational Weight Gain and Offspring Weight in Adolescence

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Abstract

Objective—To study associations of maternal gestational weight gain with offspring weight status in adolescence.

Methods—We surveyed 11,994 adolescents aged 9–14 enrolled in the Growing Up Today Study cohort and their mothers, members of the Nurses' Health Study II. We used multivariable linear and logistic regression to study associations of gestational weight gain with offspring adiposity.

Results—Mean (SD) gestational weight gain was 31.5 (11.2) pounds and offspring BMI z-score (BMI standardized for age and sex) was 0.15 (1.0) units; 6.5% of adolescents were obese (BMI greater than or equal to the 95th percentile). Gestational gain was linearly associated with adolescent adiposity: compared with 20–24 pounds, gain less than 10 pounds was associated with child BMI z-score 0.25 units lower (95% confidence interval [CI]: –0.47, –0.04), and gain greater than or equal to 45 pounds with BMI z-score 0.18 units higher (95% CI: 0.11, 0.25). Compared with women with adequate gain according to 1990 Institute of Medicine guidelines, women with excessive gain had children with higher BMI z-scores (0.14 units, 95% CI: 0.09, 0.18) and risk of obesity (odds ratio 1.42, 95% CI: 1.19, 1.70). The predicted prevalence of term low birth weight declined modestly across the range of gain (2% for gain less than 10 pounds, 1% for gain greater than or equal to 45 pounds), whereas term high birth weight increased dramatically with higher gain (10% for gain less than 10 pounds, 35% for gain of greater than or equal to 45 pounds).

Conclusion—Gestational weight gain is directly associated with BMI and risk of obesity in adolescence. Revised gestational weight gain guidelines should account for influences on child weight.

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Introduction

Gestational weight gains have increased over past decades in parallel with increases in obesity prevalence among all segments of the population, including infants and children.(1–3) In addition to the established associations of higher maternal weight gain with adverse birth outcomes, recent studies suggest that women who gain more weight during pregnancy have children who are heavier in childhood.(2,4–7) However, higher gains may prevent preterm or small for gestational age birth.(2,8) Because of the wealth of recent data regarding associations of gestational gain with short and long term outcomes, the US Institute of Medicine (IOM) is reviewing guidelines for gestational gain for the first time since 1990.(9,10)

Published studies have examined gestational weight gain as a continuous measure or in broad categories of inadequate, adequate, and excessive gain. To determine the optimal range of weight gain, however, it is necessary to study more refined categories. Thus, in the present analysis we examined maternal weight gain in 5 pound increments as well as according to the 1990 IOM recommendations. We also examined associations of maternal gain with low and high infant weight at term birth, since existing guidelines were intended to optimize size at birth and these birth outcomes have established associations with infant morbidity. We studied associations of gestational weight gain with attained weight at ages 9–14 years among 11,994 boys and girls who were born in the 1980's.

Materials and Methods

Participants were enrolled in the Growing Up Today Study (GUTS), and were offspring of women enrolled in the Nurses' Health Study II (NHS II), a cohort study of female registered nurses.(11) Study recruitment has been described in detail previously.(12) Briefly, a total of 18,526 women enrolled in NHS II provided information for 26,765 children: 13,261 girls and 13,504 boys. In the fall of 1996, we mailed surveys to these children, of whom 9,039 girls (68%) and 7,843 (58%) boys returned completed questionnaires, for a total of 16,882 participants. In 1997, 16,447 mothers (97%) completed a supplemental questionnaire regarding the child's early life. In 1999, 13,640 mothers (81%) returned a second supplemental questionnaire, which concentrated on the child's medical history and mother's prenatal diabetes and weight history. Human subject committees at the Harvard School of Public Health and Brigham and Women's Hospital, Boston, Massachusetts, approved the study.

For this analysis, of the 16,882 initially enrolled subjects we excluded 343 outside the age range 9–14 years on the baseline questionnaire, 321 who were twins or triplets, 122 born before 34 completed weeks of gestation, 547 with missing gestational age, and 162 with childhood medical conditions that might have interfered with growth, such as diabetes, juvenile rheumatoid arthritis, inflammatory bowel disease, cerebral palsy, Down Syndrome, leukemia, and other selected conditions and congenital anomalies. We also excluded 437 with missing information on height or weight in 1996, and 2,956 with missing information regarding maternal gestational weight gain. Thus, we based the present analyses on 11,994 participants. Among participants missing gestational weight gain data, 8% of children were obese, vs. 7% among participants with gestational weight gain data.

We ascertained all information from mailed self-report questionnaires. Each GUTS participant reported age, sex, race/ethnicity, height, weight, sexual maturity (Tanner stage) rating using validated pictograms,(13) age at menarche for menarcheal girls, physical activity and diet in the previous 12 months using a validated food frequency questionnaire,

(14) and average time spent watching television and videos on weekdays and on weekends.
(12)

From the 1997 supplemental questionnaire to mothers, we obtained child's birth weight, birth length, category of gestational age (<34, 34–<37, 37–<40, ≥40 weeks), medical conditions during childhood, and the duration of breast-feeding in the following categories: 0, <1, 1–3, 4–6, 7–9, and >9 months.(15) From the NHS II 1989 questionnaire and the 1999 supplemental questionnaire to mothers, we ascertained mother's history of diabetes and diagnosis of gestational diabetes during the index pregnancy, height, pre-pregnancy weight, gestational weight gain, smoking habits during the early life of the child, and birth order of the child. We excluded from analysis one woman with a calculated pre-pregnancy BMI of 70 kg/m². We ascertained the father's education status from the 1999 NHS II supplemental questionnaire and household income from the 2001 NHS II questionnaire.

Mother's pre-pregnancy weight and gestational weight gain were self-reported, as were child weight and height. Troy et al.(16) reported a high correlation between women's self-reported weight ($r = 0.87$) and height ($r = 0.94$) at age 18 years and those documented on entry to nursing school among a subset of Nurses' Health Study II participants. Similarly, in a study of mothers enrolled in NHS II and the Collaborative Perinatal project, Tomeo, et al. (17) found recall of pregnancy weight and other pregnancy-related events was reproducible and valid. However, gestational weight gain was not studied. Among adolescents, numerous investigators have found that self-reported height and weight are reliable and correlate highly with measured values, suggesting that ranking is preserved, although underreporting of weight may underestimate overweight prevalence.(18,19)

Our primary exposure of interest was maternal gestational weight gain. We modeled this variable in categories of 5 lb increments, as a continuous measure, and in categories according to 1990 IOM guidelines.(10) These guidelines recommend that women with pre-pregnancy BMI < 19.8 kg/m² should gain 28–40 pounds, BMI 19.8–26.0 kg/m² 25–35 pounds, BMI 26.1–29.0 kg/m² 15–25 pounds, and BMI > 29.0 kg/m² at least 15 pounds. For obese women, we considered gain above 25 pounds to be excessive.(4)

Because in children and adolescents BMI norms change with age and differ between the sexes, we calculated age- and sex-specific BMI z-scores by using the 2000 Centers for Disease Control and Prevention reference data, which are based on children from the 1970's and 80's.(20) These z-scores provide an age and sex independent, normally distributed measure of growth for use as an outcome. A population similar to the reference population will have a median z-score of zero, corresponding to the 50th percentile. We analyzed child BMI z-score as a continuous outcome and in categories of overweight (BMI 85th–<95th percentile), and obese (BMI ≥95th percentile), compared with BMI <85th percentile.(20)

To adjust for covariates and to account for correlated values among siblings (9,473 unique families), we used linear and logistic regression models with estimation by generalized estimating equations.(21) We adjusted all estimates for maternal age and smoking, household income and paternal education, and child race/ethnicity, gestational age, sex, age in 1996, and Tanner stage. In sequential models we further adjusted for maternal pre-pregnancy BMI (continuous), potential pathway variables (gestational diabetes, breastfeeding duration, and child behaviors including weekly hours of television and videos, physical activity, daily sugar sweetened beverage intake, and daily fried food away from home), and child birth weight. We evaluated the association of gestational weight gain with childhood weight in the full cohort, and also in analyses stratified by maternal pre-pregnancy weight. We tested effect modification with interaction terms. Using missing categories we included in multivariable analyses 2.8% of children missing information on

Tanner stage, 0.3% missing race/ethnicity, 7.0% missing paternal education, and 17.5% missing household income. Because gestation length is strongly correlated with gestational weight gain, we repeated analyses excluding preterm births.

Among 11,305 term births (≥ 37 completed weeks gestation), we also studied associations of gestational weight gain with risk of low ($< 2500\text{g}$) or high ($> 4000\text{g}$) infant weight at birth, compared with normal birth weight (2500–4000g). We adjusted these analyses for maternal, paternal, and birth characteristics. From this multivariable model, we generated predicted probabilities of low and high birth weight for each category of gestational weight gain for the typical GUTS mother: white, never smoker, husband with a college degree, household income $> \$44,500$, pre-pregnancy BMI 22.2 kg/m^2 , age at delivery 29.4 years, and gestation length ≥ 40 weeks.

Results

About 79% of mothers had a BMI $18.5\text{--}24.9\text{ kg/m}^2$ entering pregnancy, 11.3% were overweight and 3.6% were obese. Mean (SD) gestational weight gain was 31.5 (11.2) pounds, with a range from 0–100 pounds. According to the 1990 IOM guidelines, published after these pregnancies were completed, 24.5% of mothers had inadequate gain, 47.8% gained appropriate weight, and 27.8% had excessive gain. Mean (SD) offspring BMI z-score was 0.15 (1.0) units. At enrollment, 80.0% of adolescents had a normal weight (BMI $< 85^{\text{th}}$ percentile), 13.4% were overweight ($85^{\text{th}} \leq \text{BMI} < 95^{\text{th}}$ percentile), and 6.5% were obese (BMI $\geq 95^{\text{th}}$ percentile). Mothers who were obese or had never smoked gained less weight than their peers (Table 1). Maternal pre-pregnancy BMI and gestational weight gain were strong predictors of offspring obesity (Table 1).

In analyses adjusted for maternal age, smoking, and marital status, household income and paternal education, and child race/ethnicity, gestation length, sex, age, and Tanner stage, but not maternal BMI, we observed a U-shaped association between maternal gestational weight gain and child weight outcomes, with higher risk of obesity in the lowest and highest categories of maternal weight gain (Figure 1, dashed line). Further adjustment for maternal BMI inverted estimates for the lowest categories of gestational gain, but had a minimal effect for higher gains, revealing a virtually linear relationship between gestational weight gain and child BMI (Figure 1, solid line). Thus, after maternal BMI adjustment, gestational gain below 10 pounds was associated with substantially lower child BMI z-score (-0.25 , 95% CI: -0.47 , -0.04), whereas gain of at least 45 pounds was associated with substantially higher child BMI (0.18 units, 95% CI: 0.11, 0.25), each compared with gestational weight gain of 20–24 pounds, the amount of gain recommended for pregnant women in the 1970's–80's.⁽¹⁰⁾ Results were similar when we excluded children born between 34 and 37 weeks of gestation (data not shown).

In adjusted regression models, child BMI z-score increased by 0.03 units (95% CI: 0.02, 0.04) for each 5 pounds of gestational weight gain. This effect translates to about 1.3 pounds (0.6 kg) for an average 14-year-old boy or girl. Odds ratios were 1.09 (95% CI: 1.06, 1.13) for obesity and 1.05 (95% CI: 1.02, 1.07) for overweight, per 5 pounds of maternal gain. Further adjustment for potential mediators such as maternal diabetes, breastfeeding duration, child behaviors, and birth weight did not appreciably alter estimates (Table 2).

We next studied gestational gain according to 1990 IOM recommendations. Compared with women with adequate gain, women with excessive gain had children with higher z-scores (0.14, 95% CI: 0.09, 0.18) and higher odds of obesity (1.42, 95% CI: 1.19, 1.70) and overweight (1.27, 95% CI: 1.12, 1.44). Women with inadequate gain had children who were somewhat lighter, compared with women who had adequate gain (Table 2). We did not find

evidence of effect modification by maternal pre-pregnancy BMI category (p values for interaction = 0.69 for child obesity, 0.63 for child overweight, and 0.27 for child BMI z-score). Estimates appeared somewhat stronger for heavier women, although confidence intervals were broad and overlapping given the small number of women in the extreme weight categories (Table 2).

We were also interested in associations of gestational weight gain with low (<2500g) and high (>4000g) birth weight at term delivery, each compared with normal birth weight (2500 – 4000g). The likelihood of term low birth weight increased with lower gain, and the adjusted odds ratio for term low birth weight was 2.33 (95% CI: 0.46, 11.78) for gestational gain less than 10 pounds vs. 20–24 pounds. However, the overall prevalence of term low birth weight was low in this population (1.0%), and the predicted prevalence varied modestly across the range of maternal gestational weight gain, from 0.02 (95% CI: 0.00, 0.09) for gain less than 10 pounds to 0.01 (95% CI: 0.00, 0.02) for gain greater than or equal to 45 pounds (Figure 2). Term high birth weight, on the other hand, was quite common (16.2%), and risk increased markedly with higher gain, with a predicted prevalence increasing from 0.10 (95% CI: 0.06, 0.18) for gain less than 10 pounds to 0.35 (95% CI: 0.31, 0.38) for gain greater than or equal to 45 pounds (Figure 2). The adjusted odds ratio for term high birth weight was 4.14 (95% CI: 3.33, 5.15) for gain of at least 45 pounds vs. 20–24 pounds.

Discussion

In this large cohort of adolescents born in the 1980's, we observed a direct association of maternal gestational weight gain with offspring attained weight. This relationship was independent of parental characteristics, potentially mediating peripartum factors, child obesigenic behaviors, and weight at birth, suggesting a sustained effect of the intrauterine environment on offspring weight regulation.

Previous epidemiologic studies are few in number but generally consistent in finding a direct association between gestational weight gain and attained offspring weight,(4–7,22,23), although some studies have reported no association.(24,25) One small study of 110 children reported an inverse correlation, although estimates were not adjusted for maternal weight or other factors.(26) The present analysis represents a large study population evaluated in adolescence. Additional preliminary studies, presently published in abstract form only, have suggested that the direct association of higher weight gain with offspring obesity persists into adulthood.(27–29) Some preliminary studies have reported a U or J-shaped association, with greater overweight risks with the lowest and highest maternal gains, especially in women with lower pre-pregnancy BMI.(29,30) In the present analysis, an initial U-shaped association became linear after adjustment for maternal pre-pregnancy BMI.

In one preliminary study, investigators observed effect modification by maternal BMI, with stronger associations among women who were underweight prior to pregnancy.(30) In the present analysis, we did not find evidence for a different association among mothers with different weight entering pregnancy, similar to other studies.(4,7)

Gestational weight gain may be associated with offspring through several potential pathways. Mothers who gain weight readily because of genetic or lifestyle factors may have children who also are more likely to gain weight because of these same factors. The persistent relationship after adjustment for maternal BMI and child behaviors minimizes some of the effect of shared genes and extrauterine environment, and suggests that, at least in part, weight gain during pregnancy may program offspring size by modifying the intrauterine environment of the fetus. In animal models, experimental maternal overnutrition

during pregnancy results in increased fat mass, altered expression of adipogenic, lipogenic, and adipokine genes in adipose tissue, and changes in appetite centers of the brain among offspring.(34–36)

This analysis has several limitations. Residual and unmeasured confounding are a concern in all observational studies. However, adjustment for the potential sociodemographic and behavioral confounders we did measure did not have an appreciable influence on effect estimates. We were not able to account for maternal behaviors during pregnancy such as diet and physical activity, but adjustment for child behaviors did not influence estimates. We assessed some characteristics, such as household income, several years after child outcomes were collected. All weight measures were collected by self-report; heavier individuals are more likely to under-report their weight. Underreporting of gestational weight gains (especially among those who gained the most) and of child weight (especially among those who weighed the most) would most likely bias estimates toward the null. Because we did not have precise information on gestation duration, and thus could not calculate a weekly rate of gain, we were not able to evaluate risk of preterm delivery. The prevalence of term low birth weight was low in this population. Although participants lived in all 50 states, they were predominantly white, and all mothers were nurses. It is possible that associations may differ in other racial/ethnic groups or socioeconomic strata.

Any revision of recommendations for gestational weight gain must consider the range of associated short-and long-term outcomes for mother and child. Higher gestational weight gain is associated with increased risk for pregnancy complications such as cesarean or complicated vaginal delivery, and fetal macrosomia, but inversely associated with risk for small for gestational age birth.(8,37,38) Very low rates of gain may also increase risk for preterm delivery, especially among women who are underweight entering pregnancy,(4,10) although overweight women with very high gains may also be at increased risk for preterm delivery.(39) Recent large population-based studies suggest that the ideal range of gain for optimal outcomes at delivery should be lower than is currently recommended, especially for overweight and obese women.(37) For the mother, ample evidence exists to suggest that higher gain is linearly associated with postpartum weight retention and later risk for overweight, with no apparent long-term risks from lower gains.(40) Determination of the optimal range of gain will thus need to counterbalance risks of fetal growth restriction and preterm delivery against the increasingly common obesity-related conditions for both mother and child.

Once established, obesity is often recalcitrant to treatment. Identifying strategies to prevent obesity is of urgent importance. Maternal pre-pregnant weight was a strong predictor of offspring weight. Clinicians should encourage women to enter pregnancy at a healthy weight. In addition, gestational weight gain was directly and linearly associated with BMI and risk for obesity in offspring. Clinicians may find these results helpful in counseling their patients to limit their gestational weight gain. These findings may assist in ongoing efforts to determine the ideal range of gestational weight gain. They also point to the need for effective interventions to moderate gestational weight gain to help curtail the risk of later obesity for mothers and their children.

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References

1. Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999–2004. *JAMA* 2006;295:1549–1555. [PubMed: 16595758]
2. Hayes, M.; Abrams, B.; Davidson, EC., et al., editors. *Influence of Pregnancy Weight on Maternal and Child Health*. Washington, D.C: National Academies Press; 2007.
3. Kim J, Peterson KE, Scanlon KS, et al. Trends in overweight from 1980 through 2001 among preschool-aged children enrolled in a health maintenance organization. *Obesity* 2006;14:1107–1112. [PubMed: 16899790]
4. 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;196 322 e1-8.
5. Moreira P, Padez C, Mourao-Carvalho I, Rosado V. Maternal weight gain during pregnancy and overweight in Portuguese children. *Int J Obes (Lond)* 2007;31:608–614. [PubMed: 17384661]
6. Li C, Goran MI, Kaur H, Nollen N, Ahluwalia JS. Developmental trajectories of overweight during childhood: role of early life factors. *Obesity* 2007;15:760–771. [PubMed: 17372328]
7. Wrotniak BH, Shults J, Butts S, Stettler N. Gestational weight gain and risk of overweight in the offspring at age 7 y in a multicenter, multiethnic cohort study. *Am J Clin Nutr* 2008;87:1818–1824. [PubMed: 18541573]
8. Viswanathan, M.; Siega-Riz, AM.; Moos, M-K., et al. *Outcomes of Maternal Weight Gain, Evidence Report/Technology Assessment No. 168*. Rockville, MD: Agency for Healthcare Research and Quality; 2008.
9. Elliott, VS. Pregnancy weight gain due for review. 2007 Sep 10 [Accessed October 10, 2007]. Available at: <http://www.ama-assn.org/amednews/2007/09/10/hlsc0910.htm>.
10. Institute of Medicine. *Nutrition during pregnancy*. Washington, DC: National Academy Press; 1990.
11. Rich-Edwards JW, Goldman MB, Willett WC, et al. Adolescent body mass index and infertility caused by ovulatory disorder. *Am J Obstet Gynecol* 1994;171:171–177. [PubMed: 8030695]
12. Mayer-Davis EJ, Rifas-Shiman SL, Zhou L, Hu FB, Colditz GA, Gillman MW. Breast-feeding and risk for childhood obesity. *Diabetes Care* 2006;29:2231–2237. [PubMed: 17003298]
13. Morris N, Udry J. Validation of a self-administered instrument to assess stage of adolescent development. *J Youth Adol* 1980;9:271–280.
14. Rockett HR, Breitenbach M, Frazier AL, et al. Validation of a youth/adolescent food frequency questionnaire. *Prev Med* 1997;26:808–816. [PubMed: 9388792]
15. Gillman MW, Rifas-Shiman SL, Camargo CA Jr, et al. Risk of overweight among adolescents who were breastfed as infants. *JAMA* 2001;285:2461–2467. [PubMed: 11368698]
16. Troy LM, Hunter DJ, Manson JE, Colditz GA, Stampfer MJ, Willett WC. The validity of recalled weight among younger women. *Int J Obes Relat Metab Disord* 1995;19:570–572. [PubMed: 7489028]
17. Tomeo CA, Rich-Edwards JW, Michels KB, et al. Reproducibility and validity of maternal recall of pregnancy-related events. *Epidemiology* 1999;10:774–777. [PubMed: 10535796]
18. Tokmakidis SP, Christodoulos AD, Mantzouranis NI. Validity of self-reported anthropometric values used to assess body mass index and estimate obesity in Greek school children. *J Adolesc Health* 2007;40:305–310. [PubMed: 17367722]
19. Elgar FJ, Roberts C, Tudor-Smith C, Moore L. Validity of self-reported height and weight and predictors of bias in adolescents. *J Adolesc Health* 2005;37:371–375. [PubMed: 16227121]
20. National Center for Health Statistics. *CDC Growth Charts, United States. 2000*. Available at: <http://www.cdc.gov/growthcharts/>
21. Liang KY, Zeger SL. Longitudinal data analysis using generalized linear models. *Biometrika* 1986;73:13–22.
22. Vohr BR, McGarvey ST, Tucker R. Effects of maternal gestational diabetes on offspring adiposity at 4–7 years of age. *Diabetes Care* 1999;22:1284–1291. [PubMed: 10480772]

23. Fisch RO, Bilek MK, Ulstrom R. Obesity and leanness at birth and their relationship to body habitus in later childhood. *Pediatrics* 1975;56:521–528. [PubMed: 1165956]
24. Maffei C, Micciolo R, Must A, Zaffanello M, Pinelli L. Parental and perinatal factors associated with childhood obesity. *Int J Obes Relat Metab Disord* 1994;18:301–305. [PubMed: 8061723]
25. Whitaker RC. Predicting preschooler obesity at birth. *Pediatrics* 2004;114:e29–e36. [PubMed: 15231970]
26. Esposito-Del Puente A, Scalfi L, De Filippo E, et al. Familial and environmental influences on body composition and body fat distribution in childhood in southern Italy. *Int J Obes Relat Metab Disord* 1994;18:596–601. [PubMed: 7812412]
27. Schack-Nielsen LME, Michaelsen KF, Sorensen TIA. High maternal pregnancy weight gain is associated with an increased risk of obesity in childhood and adulthood independent of maternal BMI. *Pediatr Res* 2005;58:1020. [abstract].
28. Seidman DS. Excessive maternal weight gain during pregnancy and being overweight at 17 years of age. *Pediatr Res* 1996;39:112A. [abstract]. [PubMed: 8825394]
29. Stuebe A, Michels K. Gestational weight gain and obesity at age 18 in the daughter. *American Journal of Obstetrics and Gynecology* 2006;195:S228. [abstract].
30. Sharma AJ, Cogswell ME, Grummer-Strawn LM. The association between pregnancy weight gain is associated with an increased risk of obesity in childhood and adulthood independent of maternal BMI. *Pediatr Res* 2005;58:1038. [abstract].
31. Silverman BL, Rizzo TA, Cho NH, Metzger BE. Long-term effects of the intrauterine environment. *Diabetes Care* 1998;21 Suppl 2:B142–B149. [PubMed: 9704242]
32. Dabelea D, Hanson RL, Lindsay RS, et al. Intrauterine exposure to diabetes conveys risks for type 2 diabetes and obesity: a study of discordant sibships. *Diabetes* 2000;49:2208–2211. [PubMed: 11118027]
33. Plagemann A. Perinatal nutrition and hormone-dependent programming of food intake. *Horm Res* 2006;65 Suppl 3:83–89. [PubMed: 16612119]
34. Muhlhausler BS. Programming of the appetite-regulating neural network? *J Neuroendocrinol* 2007;19:67–72. [PubMed: 17184487]
35. Muhlhausler BS, Adam CL, Findlay PA, Duffield JA, McMillen IC. Increased maternal nutrition alters development of the appetite-regulating network in the brain. *Faseb J* 2006;20:1257–1259. [PubMed: 16684802]
36. Muhlhausler BS, Duffield JA, McMillen IC. Increased maternal nutrition increases leptin expression in perirenal and subcutaneous adipose tissue in the postnatal lamb. *Endocrinology* 2007;148:6157–6163. [PubMed: 17884936]
37. Kiel DW, Dodson EA, Artal R, Boehmer TK, Leet TL. Gestational weight gain and pregnancy outcomes in obese women. *Obstet Gynecol* 2007;110:752–758. [PubMed: 17906005]
38. Devader SR, Neeley HL, Myles TD, Leet TL. Evaluation of gestational weight gain guidelines for women with normal prepregnancy body mass index. *Obstet Gynecol* 2007;110:745–751. [PubMed: 17906004]
39. Schieve LA, Cogswell ME, Scanlon KS. Maternal weight gain and preterm delivery: differential effects by body mass index. *Epidemiology* 1999;10:141–147. [PubMed: 10069249]
40. Siega-Riz AM, Evenson KR, Dole N. Pregnancy-related weight gain--a link to obesity? *Nutr Rev* 2004;62:S105–S111. [PubMed: 15387475]

Figure 1.

Associations of maternal gestational weight gain with child BMI z-score, with and without adjustment for maternal pre-pregnancy BMI. All estimates are adjusted for maternal age, race/ethnicity, and marital status; household income and paternal education; and child sex, gestation length, age and Tanner stage at outcome assessment. BMI: body mass index.

Figure 2.

Predicted probabilities of birth weight > 4000g, and birth weight < 2500g among term births, according to maternal gestational weight gain. We predicted probabilities for the typical Growing Up Today Study mother: white, never smoker, husband with a college degree, household income over \$44,500, pre-pregnancy BMI 22.2 kg/m², age at delivery 29.4 years, and gestation length greater than or equal to 40 weeks. BMI: body mass index.

Table 1

Maternal gestational weight gain and child obesity prevalence according to maternal and child characteristics among 11,994 mother-child pairs in the Growing Up Today Study.

	N (%)	Mean maternal gestational weight gain (pounds) (SD)	% of children with BMI $\geq$ 95 th percentile
Maternal characteristics			
Pre-pregnancy BMI (kg/m ²)			
Underweight (< 18.5)	720 (6.0)	31.1 (11.1)	1.9
Normal (18.5 – 24.9)	9497 (79.0)	31.7 (10.8)	5.2
Overweight (25 – 29.9)	1,350 (11.3)	31.4 (12.2)	12.7
Obese ($\geq$ 30)	427 (3.6)	25.6 (14.1)	24.6
Age at delivery (yrs)			
< 25	1,194 (10.0)	32.4 (12.7)	6.1
25 – 34	9,963 (83.1)	31.4 (11.0)	6.5
$\geq$ 35	837 (7.0)	30.5 (11.2)	7.4
Diabetes status			
Normal	11,538 (96.2)	31.4 (11.1)	6.5
Gestational	350 (2.9)	30.9 (12.0)	6.3
Preexisting diabetes	43 (0.4)	34.1 (11.3)	16.3
Missing	63 (0.5)	39.0 (17.2)	11.1
Smoking			
Never smoked	8,404 (70.2)	30.6 (10.6)	6.4
Quit $\geq$ 1y	2,329 (19.4)	33.2 (11.5)	6.2
During pregnancy	1,247 (10.4)	33.8 (13.2)	8.4
Household income (1991 dollars, pre-tax)			
$\leq$ 44,500	1,254 (10.5)	31.5 (12.6)	9.1
> 44,500	8,638 (72.0)	31.6 (11.1)	6.1
Missing	2,102 (17.5)	30.8 (10.7)	6.9
Husband Education			
Graduate degree	3,624 (30.2)	31.6 (10.8)	5.2
College graduate	5,561 (46.4)	31.3 (11.1)	6.6
$\leq$ High school	1,968 (16.4)	31.3 (11.6)	8.3
Missing	841 (7.0)	32.3 (12.1)	8.2
Gestational weight gain, pounds			
< 10	87 (0.73)	--	16.1
10–14	212 (1.8)	--	9.9
15–19	731 (6.1)	--	5.3
20–24	1,751 (14.6)	--	5.9
25–29	2,419 (20.2)	--	6.3
30–34	2,546 (21.2)	--	5.3

	N (%)	Mean maternal gestational weight gain (pounds) (SD)	% of children with BMI $\geq$ 95 th percentile
35–39	1,335 (11.1)	--	6.4
40–44	1,338 (11.2)	--	6.4
≥ 45	1,575 (13.1)	--	9.5
Child characteristics			
Race/ethnicity			
White	11,207 (93.4)	31.4 (11.1)	6.5
Other	753 (6.3)	31.8 (11.7)	7.7
Missing	34 (0.3)	32.5 (12.2)	11.8
Sex			
Female	6,411 (53.5)	31.2 (11.1)	4.7
Male	5,583 (46.6)	31.7 (11.3)	8.7
Gestational age (weeks)			
≥ 40	7,880 (65.7)	32.1 (11.2)	6.5
37 – <40	3,425 (28.6)	30.4 (10.7)	6.0
34 – <37	689 (5.7)	29.0 (12.1)	9.4
Breastfeeding duration (months)			
Never breastfed	1,367 (11.4)	30.7 (11.8)	8.1
< 1	582 (4.9)	31.6 (11.9)	10.1
1 – 3	1,797 (15.0)	32.0 (12.2)	8.1
4 – 6	2,457 (20.6)	31.8 (11.1)	6.4
7 – 9	1,837 (15.4)	31.3 (10.6)	6.0
> 9	3,911 (32.7)	31.3 (10.6)	5.1
Child characteristics in 1996			
Age (years)			
9	1,465 (12.2)	31.3 (10.9)	7.4
10	2,404 (20.0)	31.7 (11.0)	8.0
11	2,459 (20.5)	31.5 (11.1)	6.5
12	2,201 (18.4)	31.4 (11.3)	5.8
13	1,999 (16.7)	31.5 (11.2)	6.3
14	1,466 (12.2)	31.0 (11.6)	5.0
Tanner stage			
1	2,733 (22.8)	31.4 (10.8)	6.6
2	2,926 (24.4)	31.6 (11.3)	7.2
3	2,138 (17.8)	31.3 (11.3)	6.2
4	2,525 (21.1)	31.4 (11.0)	5.8
5	1,341 (11.2)	31.7 (12.1)	6.6
Missing	331 (2.8)	30.6 (10.1)	7.6
BMI percentile			

	N (%)	Mean maternal gestational weight gain (pounds) (SD)	% of children with BMI $\geq$ 95 th percentile
< 85 th	9606 (80.0)	31.2 (10.8)	--
85 th – < 95 th	1,603 (13.4)	32.2 (11.9)	--
$\geq$ 95 th	785 (6.5)	32.9 (13.4)	--

Table 2

Associations of maternal gestational weight gain with childhood obesity, overweight, and BMI z-score

	Obesity (BMI $\geq$ 95th %ile)	Overweight (BMI 85th – <95th %ile)	BMI z-score
	Odds Ratio (95% CI)	Odds Ratio (95% CI)	Beta coefficient (95% CI)
Total gestational gain (effect per 5 pounds)			
Adjusted estimate [†]	1.09 (1.06, 1.13)	1.05 (1.02, 1.07)	0.03 (0.02, 0.04)
Additional adjustment for maternal diabetes, breastfeeding duration, and child behaviors	1.10 (1.06, 1.13)	1.05 (1.03, 1.08)	0.03 (0.03, 0.04)
Additional adjustment for birth weight	1.08 (1.05, 1.13)	1.05 (1.03, 1.08)	0.03 (0.02, 0.04)
Stratified by pre-pregnancy BMI (adjusted[†] effect per 5 pounds)			
< 18.5 kg/m ²	0.71 (1.23, 1.91)	1.04 (0.90, 1.20)	−0.01 (−0.04, 0.03)
18.5 – 24.9 kg/m ²	1.09 (1.04, 1.14)	1.03 (1.00, 1.07)	0.03 (0.02, 0.04)
25.0–29.9 kg/m ²	1.11 (1.04, 1.19)	1.07 (1.02, 1.13)	0.04 (0.02, 0.06)
$\geq$ 30 kg/m ²	1.04 (0.95, 1.15)	1.04 (0.95, 1.14)	0.10 (−0.09, 0.28)
Gain per 1990 IOM recommendations			
Inadequate	0.91 (0.74, 1.13)	0.97 (0.84, 1.12)	−0.06 (−0.10, −0.01)
Adequate	1.0 (referent)	1.0 (referent)	0 (referent)
Excessive	1.42 (1.19, 1.70)	1.27 (1.12, 1.44)	0.14 (0.09, 0.18)

[†] All estimates are adjusted for maternal age, pre-pregnancy BMI, and smoking during pregnancy; household income and paternal education; and child gestational age, race/ethnicity, sex, age, and Tanner stage at outcome.