Published in final edited form as:

J Hum Nutr Diet. 2017 February ; 30(1): 51–58. doi:10.1111/jhn.12398.

Association between gestational weight gain and risk of obesity in preadolescence: a longitudinal study (1997–2007) of 5,125 children in Greece

Stamatis P. Mourtakos¹, Konstantinos D. Tambalis^{1,2}, Demosthenes B. Panagiotakos¹, George Antonogeorgos¹, Chrysoula D. Alexi¹, Michael Georgoulis¹, George Saade³, and Labros S. Sidossis^{1,4}

¹Department of Nutrition and Dietetics, Harokopio University, Athens, Greece

²Department of Physical Education and Sport Science, University of Athens, Athens, Greece

³Department of Obstetrics and Gynecology, University of Texas Medical Branch at Galveston, Texas, USA

⁴Department of Internal Medicine, Sealy Center on Aging, Institute for Translational Sciences and Shriners Hospital for Children, University of Texas Medical Branch at Galveston, Texas, USA

Abstract

Objective—To study the association between gestational weight gain (GWG) and birth weight as well as Body Mass Index (BMI) status of children at the age of 2 and 8.

Methods—Population-based data were obtained from a database of all 7–9 years old Greek children who attended primary school during 1997–2007. The study sample consisted of 5,125 children matched with their mothers, randomly selected according to region and place of residence and equally distributed (approximately 500 per year) throughout the study period (1997–2007). A standardised questionnaire was applied; telephone interviews were carried out to collect maternal age, BMI status at the beginning and the end of pregnancy and GWG, offspring's birth weight and BMI status at the ages of 2 and 8 years, as well as several other pregnancy characteristics (e.g., pregnancy duration, gestational medical problems, maternal smoking and alcohol consumption habits and offspring's lactation after pregnancy).

Labros S. Sidossis, PhD, University of Texas Medical Branch at Galveston, 301 University Blvd, Galveston Texas, 77555-0177, Ph: 409-266-9690, lasidoss@utmb.edu.

Conflict of Interest:

The authors report no conflict of interest in the reporting of the data.

Ethical standards

The study was approved by the Bioethics Committee of Harokopio University. Oral approval was obtained from all mothers who agreed to participate in the study and written informed consent was obtained from those participants who took part in the validation process of the study.

Authors' contributions

All authors contributed to the interpretation of the analysis and critically revised the manuscript. SM, DP, GS, KT and LS guided the design, analysis, interpretation and writing of the manuscript. GS, KT and GA revised the manuscript during the review process and performed the statistical analysis. MG, SM, CA and conducted the individual interviews, read the transcripts, and developed the analytical framework. All authors read and approved the final manuscript.

Results—GWG was positively associated with the offspring's weight status at all three life stages studied, i.e., newborn (birth weight), infant (BMI) and child (BMI) ($b=0.008\pm0.001$, $b=0.053\pm0.009$ and $b=0.034\pm0.007$, respectively, all $p<0.001$), after adjusting for maternal age at pregnancy (significant inverse predictor only at age 2). The same applied to excessive GWG, as defined by the Institute of Medicine guidelines.

Conclusion—Excessive GWG was associated with higher risk of greater infant size at birth and higher BMI status at the ages of 2 and 8. Health care providers should encourage women to limit their GWG to the range indicated by current guidelines.

Keywords

childhood obesity; pregnancy; maternal weight gain; IOM category; newborn; infant; child; preadolescence

Introduction

Childhood obesity is a recognised epidemic in most developed and developing countries (1). The number of children who are overweight is expected to rise by 1.3 million per year and more than 300,000 become obese each year (2). Childhood obesity rates in Greece are among the highest not only in Europe (3), but also worldwide and similar to those of the USA (4). In particular, we recently reported a dramatic increase (by 52%) in the prevalence of childhood obesity in Greece (3). Furthermore, a significant increase was observed, by approximately 30%, in the rates of overweight 8 to 9 year old children of both genders in Greece during the last decade (3, 5).

Obesity during adulthood often has its roots in childhood (6). Therefore, understanding the determinants of childhood obesity will have broad implications for health. One of the factors contributing to childhood obesity, which is intensively researched lately, is prenatal maternal characteristics. Observational studies suggest that childhood obesity could be associated with specific characteristics of pregnancy, such as maternal weight status, gestational weight gain (GWG), infant birth weight, smoking habits during pregnancy, maternal gestational diabetes and breast feeding (7–9), while GWG has also been associated with greater offspring body mass index (BMI) into early adulthood (10). Assessment of the Institute of Medicine (IOM) recommendations revealed that 42% of women in the USA began pregnancy in 2004–2007 as overweight or obese and 51.2% gained excessive weight (>50 pounds) during their pregnancy (11).

In spite of the alarming rates of obesity in various countries, there is a limited number of studies which provide evidence related to the effect of the gestational period and the related maternal characteristics with the offspring's weight status in preadolescence. Moreover, the consistency of this effect across time and offspring age has never been evaluated. Therefore, the aim of the present study was to determine the effect of GWG on the offspring's weight status at different life stages (e.g., newborn, 2 and 8 years) and explore the consistency of this association across time (e.g., 1997–2007) and offspring age.

Methods

A health survey in Greek primary schools (1997 – 2007)

During the years 1997–2007, with the exception of 2002, 11 nationwide, school-based health surveys were performed (i.e., 85% participation rate for schools); schools that did not participate were from borderland areas, with small numbers of children. A total of 671,715 primary school pupils, aged 7–9 years old, were enrolled (51% boys and 49% girls). Socio-demographic (age, gender, city and area of school and contact information for children), anthropometric (weight in kg, height in cm) and physical activity data were obtained from almost all children who went to the primary school in these years (87% participation rate). Measurements were performed by two trained Physical Education (PE) teachers in each school and were collected yearly, during the spring of each year. PE teachers followed a specific protocol taught in corresponding seminars held by the Greek General Secretariat of Sports. Following an official request to the Ministry of Education, the database was obtained by our study group in order to test several research hypotheses.

Working sample

To test the research hypothesis, a sample of 5,500 children (0.8% of the enrolled population) was randomly extracted from the database after the completion of the 1997–2007 school-based health surveys. Random extraction was performed through SPSS statistical software. The number of 5,500 subjects was adequate to achieve statistical power greater or equal to 99% for evaluating a 0.10 ± 0.05 change in the regression coefficients at 5% significance level of two-sided tested hypotheses. The random sampling was stratified according to the region and place of living (e.g., rural/urban), according to the National Statistical Agency and equally distributed during the study period (i.e., 500 mothers per year). For each child, a telephone interview with their mothers was requested by the study's investigators. Of the 5,500 mothers, 192 (3.5%) did not provide full information about their children and 183 (3.3%) did not want to participate; thus, 5,125 mother-child dyads that covered all geographical regions of Greece (e.g., mainland Greece and the islands), participated in the current work. All mothers had Greek nationality. Originally, 7,500 children and their families were randomly extracted from the database through stratified random sampling and contacted by our research team. From them, 5500 (73%) agreed to participate in the study. No specific information regarding the characteristics among the responders and the non-responders group are available. However, the non responding rate showed no differences among the sampling strata, thus minimizing any selection bias in the final sample.

Measurements

The information needed to test the research hypothesis was obtained using a standardised questionnaire, the Childhood Obesity Pregnancy Determinants (ChOPreD) questionnaire, designed and developed in collaboration with the Department of Nutrition and Dietetics of Harokopio University and the Department of Internal Medicine-Geriatrics, Sealy Centre on Aging at the University of Texas Medical Branch. The ChOPreD questionnaire was tested and internally revised by the study investigators during a pilot study, which confirmed its construct validity. Moreover, in order to validate the telephone interview process, 100 face-to-face interviews were conducted to check for discrepancies with the information collected

through the telephone. No such discrepancies were noted in any variables measured (all $p > 0.90$).

The information obtained was: mother's nationality (Greek or other), parents' educational level, duration of pregnancy (in weeks), potential medical problems during pregnancy (i.e., development of diabetes, hypertension), lifestyle behaviours during pregnancy (smoking, alcohol consumption and eating habits), physical exercise during pregnancy, maternal lactation after pregnancy, and parental anthropometric data. With regard to anthropometric evaluation, mothers were asked to report their body weight at the beginning and the end of the pregnancy, as recorded in their prenatal records (e.g., ultrasounds). GWG was calculated based on the difference between the mother's weight at the last and first visits. Only mothers that had Greek nationality and had full-term pregnancy (e.g., duration > 37 weeks) were retained in the study. Relative GWG was calculated based on the difference between the last visit compared to the first. Each mother was categorized according to the IOM guidelines: (1) for mothers who are underweight at the start of pregnancy, adequate GWG is 12.5–18 kg; (2) for mothers at normal weight at the start of pregnancy, adequate GWG is 11.5–16 kg; (3) for mothers who are overweight at the start of pregnancy, adequate GWG is 7–11.5 kg; and (4) for mothers who are obese at the start of pregnancy, adequate weight gain is 5–9 kg. Mothers who gained more or less weight than the aforementioned were categorised as IOM excess or inadequate, respectively (12).

Moreover, children's anthropometric data, such as height and weight, at various developmental age stages (e.g., birth, 2 years and 8 years) were also recorded. The data for the children were retrieved from two sources: mothers were asked to provide information that related to their child's birth weight and height, and their height and weight at the age of 2 years as they appeared in the health records for each child. The weight and height at the age of 8 was retrieved from the records of the database (measured by the investigators). BMI status of the offspring at the age of 2 and 8 was determined based on age- and sex-specific cut-off points suggested by the International Obesity Task Force (IOTF) (13).

The study was approved by the Bioethics Committee of Harokopio University. Oral approval was obtained from all mothers who agreed to participate in the study and written informed consent was obtained from those participants who took part in the validation process of the study.

Statistical analysis

Continuous variables are presented as median and quartiles (1st–3rd) or mean and standard deviation. Categorical variables are presented as absolute and relative frequencies. Histograms and P-P plots were applied to evaluate the normality of the distribution of the continuous variables. To test the research hypothesis, multiple linear regression analysis, with the offspring's birth weight or BMI at the age of 2 and 8 as the dependent outcome, was carried out with the following independent variables: maternal age and GWG (Model 1) and maternal age and IOM Category (Excess) (Model 2). Normality of the residuals derived from the linear regression models were tested using the Kolmogorov-test and P-P plots; homoscedasticity was evaluated by fitting scatterplots of standardised residuals against predicted values. The Variance Inflation Factor (VIF) was calculated to test for colinearity of

the independent variables and the Durbin-Watson criterion was applied to evaluate serial dependency of BMI. The annual effect of the association of maternal age and GWG with BMI at the age of 2 and of 8 years was studied during the entire 10 year period, using linear trend analysis. In order to assess the potential effect of maternal age and GWG on the obesity status (e.g., overweight/obese vs. normal) of the offspring, logistic regression analysis was applied and odds ratios (ORs) with their corresponding 95% confidence intervals (CIs) were calculated. Hosmer and Lemeshow's test was calculated in order to evaluate the model's goodness-of-fit and residual analysis was implicated using the dbeta, the leverage, and Cook's distance D statistics in order to identify outliers and influential observations. All analyses were performed using the SPSS version 18.0 software for Windows (SPSS Inc., Chicago, IL, USA). Statistical significance level from two-sided hypotheses was accepted at the 5% level ($p \leq 0.05$).

Results

The characteristics of the studied mothers and their offspring are presented in Table 1. The median maternal age at pregnancy was 28 years (1st, 3rd quartile 25, 30), the maternal age range was 15 – 48 years. The median GWG was 13 kg (1st, 3rd tertile 10, 18) with a mean of 14.3 ± 3.45 kg (range 5 – 45 kg), while the median relative GWG (over maternal weight at first visit) was 21.7% for the entire sample, 27.9% (1st, 3rd tertile: 21.2%, 40.0%) for underweight mothers, 22.0% (17.5%, 30.0%) for normal weight mothers, 18.6% (14.0%, 25.7%) for overweight mothers and 12.9% (9.7%, 18.8%) for obese mothers. The majority of mothers started their pregnancy with normal BMI (79.9%), 3.8% were underweight, 14.8% were overweight and 2.5% were obese. However, 48.1% of mothers were overweight at the end of the pregnancy, 26.5% were obese and only 25.4% retained a normal BMI. As far as IOM category is concerned, 34.1% of the mothers gained adequate/normal weight during pregnancy, while 31.5% gained less and 34.4% gained more than recommended. The offspring had an average birth weight of 3.33 ± 0.50 kg, ranging from 1.20 kg to 5.80 kg. The mean BMI at the age of 2 (infant), and at the age of 8 (child) were 16.5 ± 2.28 kg/m² and 17.6 ± 3.01 kg/m² respectively.

Results from the multiple linear regression analysis (Table 2) revealed that GWG change was positively associated with offspring's birth weight and BMI at age of 2 and 8 years (Model 1); no association was observed with maternal age, except for offspring's BMI at age 2. Moreover, excess weight gain according to IOM Categories (Model 2) was associated with birth weight or BMI at different life stages (i.e., at the age of 2 and 8 years), after adjusting for maternal age. The adjusted R squared for Model 1 was 0.9% for newborns (F-statistic: 23.730, p-value <0.001), 2.9% for infants aged 2 years (F-statistic: 24.007, p-value <0.001) and 5% (F-statistic: 11.760, p-value <0.001) for children aged 8 years, which indicates that change in GWG explains a considerable and gradually higher proportion of the variance in offspring BMI level at the various ages. Similar pattern was observed for Model 2, for which the adjusted R square was 0.1% for newborns (F-statistic: 1.759, p-value <0.172), 2% for infants aged 2 years (F-statistic: 11.038, p-value <0.001) and 6% (F-statistic: 10.592, p-value <0.001) for children aged 8 years.

Trend analysis revealed that the effect of maternal age or GWG during pregnancy on offspring BMI status at 2 or 8 years was similar across time (1997–2008), i.e., no significant linear slope (trend) was revealed on the beta-coefficients of the applied models (all p-values >0.05).

The aforementioned analyses were also stratified by maternal body weight status at the beginning of pregnancy (i.e., underweight, normal weight, overweight and obese). It was observed that the effect of GWG on infant birth-weight was statistically significant for normal weight (0.008 ± 0.001 , $p < 0.001$) and overweight mothers (0.008 ± 0.003 , $p = 0.014$), per 1 kg gain, but not significant for underweight and obese mothers. The effect of GWG on BMI status at age 2 years was statistically significant for normal weight mothers at 0.056 ± 0.010 ($p < 0.001$) per 1 kg gain and for overweight mothers at 0.061 ± 0.026 ($p = 0.020$) per 1 kg gain, but not significant for underweight and obese mothers; the effect of GWG on BMI status at age 8 was 0.079 ± 0.029 ($p = 0.006$) per 1 kg gain for underweight mothers, 0.033 ± 0.008 ($p = 0.0005$) for normal weight and 0.059 ± 0.020 ($p = 0.003$) for overweight mothers, but not significant for obese mothers.

Logistic regression analysis was conducted to assess the potential effect of maternal age and GWG on the probability of overweight and obesity of the offspring at the age of 2 and 8. The analysis revealed that 1 kg weight gain during pregnancy was significantly associated with 1.054-times higher odds of the offspring being overweight (95%CI: 1.022, 1.087) at the age of 2, 1.036-times higher odds (95%CI: 1.014, 1.058) at the age of 8, as well 1.077-times higher odds of the offspring being obese (95%CI: 1.046, 1.109) at the age of 2 and 1.048-times higher odds (95%CI: 1.024, 1.072) at the age of 8, after adjusting for maternal age.

Furthermore, a 10% relative increase in maternal body weight as compared to weight at first visit was associated with a 42% higher likelihood of the offspring being overweight/obese at the age of 2 years (95%CI: 28%, 59%), while relative GWG was not significantly associated with offspring's obesity status at the age of 8 years. When the previous analysis was stratified by maternal obesity status at the beginning of pregnancy (i.e., underweight, normal weight, overweight and obese) we found that relative GWG was associated with an increased likelihood of having an overweight/obese offspring at the age of 2 years for underweight (OR per 10% change: 1.42; 95%CI: 1.00, 1.96), normal weight (OR 1.45; 95%CI: 1.28, 1.64), as well as overweight mothers (OR 1.79; 95%CI: 1.21, 1.67), but not for obese ones (OR 1.00; 95%CI: 0.97, 1.87). No significant effect of maternal relative GWG was observed on offspring obesity status at the age of 8 when the analysis was stratified by maternal obesity status at the beginning of pregnancy (e.g., all $p > 0.05$). When the analysis was focused on birth weight, relative GWG was positively associated with infant weight for normal weight mothers (0.003 ± 0.001 , $p < 0.001$) and overweight mothers (0.004 ± 0.002 , $p = 0.041$), but not for underweight mothers (0.0002 ± 0.002 , $p = 0.339$) or obese mothers (0.006 ± 0.005 , $p = 0.254$).

Discussion

The aim of the present study was to determine how GWG is related to the offspring's weight status at different life stages (e.g., newborn, 2 and 8 years) and explore the consistency of

this association across time. The results of the present study revealed that excessive GWG (expressed as an absolute scale or based on IOM recommendations) in Greek women was positively associated with the risk of obesity at all three stages of their offspring's life that were studied (e.g., newborn, infant and child), irrespectively of maternal age. With respect to consistency over time, there were no changes in the effect of maternal age and GWG on the weight status of the offspring throughout the decade studied (1997–2007).

There are many mechanisms by which a mother's increased GWG in pregnancy might confer risk of obesity to her child, including the child's inheritance of genes that confer susceptibility to obesity, the effects of maternal increased weight on the intrauterine environment, and the maternal role in shaping the child's postnatal eating and physical activity environment. Regardless of the exact mechanisms, the presence of obesity is associated with various metabolic and vascular abnormalities in childhood. Therefore, the prevention of the offspring's obesity through modification of the mother's pre- and perinatal characteristics is of great public health importance (14–16). It is also worth mentioning that, besides offspring weight status, higher maternal prepregnancy BMI has been associated with higher systolic blood pressure, insulin, glucose and insulin resistance levels in adolescence, indicating an adverse cardiometabolic profile (17). The results of the present study suggest the need for pregnant women to adhere to recommended GWG.

Epidemiological support for the hypothesis that GWG is associated with the offspring's future obesity status comes from studies that showed a positive correlation between maternal BMI before pregnancy or in its early stages and the BMI of the offspring in later life (18–22). For example, in a study based on reports of families who participated in the Special Supplemental Nutrition Programme for women, infants and children in Ohio, (with a sample of more than 5,000 children), strong and linear correlations were found between maternal BMI during the first trimester of pregnancy and the risk of developing childhood obesity until the age of 4 years old (18). This relationship was independent of a range of other factors, such as birth weight, socio-economic status and maternal smoking status during pregnancy.

Two epidemiological studies that examined the relationship between GWG and weight of the child at the age of 3 years reported that GWG is linked to a higher risk for obesity in childhood. The first study involved 1,044 mother-child pairs. Women with adequate or excess GWG had about 4 times greater risk of having a child with BMI above the 95th percentile compared with women whose GWG was under the levels suggested by IOM (23). The second study examined 208 mother-child pairs in rural areas of upstate New York and found a significant interaction between maternal BMI before pregnancy, the GWG, and the weight of the child at the age of 3 years. Although the authors did not find an independent effect of GWG on offspring's weight in their overall multivariate model, they attributed this to their small sample size. The authors determined the risks of childhood obesity based on GWG as well as the BMI before pregnancy (24). Other researchers have studied the connection of GWG and obesity in older children/adolescents. Oken et al. (25) examined approximately 12,000 children aged 9–14 years and found that every 5-lb increase in the GWG was associated with 1.09 OR of obesity of the offspring. Compared with GWG in the IOM guidelines in 1990, an increase over the guidelines was associated with a 1.42 OR of

developing obesity. Maternal BMI before pregnancy did not alter the relationship between childhood obesity and GWG.

The current research revealed that the median GWG was 13 kg and that, based on the 2009 IOM recommendations, 62.6% of the mothers gained adequate/normal weight during pregnancy, while 34.4% gained excess weight. Egan et al. (26) noted an excessive GWG in 59% of women, Chung et al. (27) noted 73%, Walsh et al. (28) 43% and He et al. (29) 14%. The differences between populations may be due to under-reporting of GWG by some, or that some populations are properly informed and advised by their physicians or are more sensitive to weight gain for various reasons.

Besides the absolute GWG, our study indicated that maternal excess GWG according to IOM recommendations was also related to an increased risk of having an offspring with higher weight at birth and higher BMI at the age of 2 and 8. This is in accordance with the findings reported by the prospective national Norwegian Mother and Child Cohort Study (MoBa), which involved 56,101 pregnant women. This study reported that weight gain in excess of the IOM recommendations (e.g., GWG>IOM rec.) among other variables (e.g., pregnancy hypertension, etc.) significantly increased the risk for a high birth weight infant (30). Moreover, in the prospective study conducted by Alberico et al.(31), which collected data on mode of delivery and maternal/neonatal outcomes in eleven hospitals in Italy, the researchers reported that maternal obesity, excess GWG and diabetes should be considered as independent risk factors for newborn macrosomia. They reported significant ORs of developing offspring macrosomia for pre-gestational BMI overweight and obese mothers, and for GWG that is higher than IOM recommendations. Moreover, Walsh et al. (28) report that women with excessive weight gain during pregnancy had higher foetal weights and foetal adiposity, while infant birth weight and birth weight centiles were also higher in those who exceeded the guidelines.

The major strength of our study is the fact that it explored the potential association between GWG and the offspring's weight status at three different developmental stages (e.g., newborn, 2 and 8 years) and explored the consistency of this association across time (e.g., 1997–2007). However the current study has limitations. The information that was collected during the telephone interviews was self-reported, and although mothers could provide information based on health records for themselves and their children, this constitutes a limitation of the study. Moreover, in the current cohort, 17.3% of women were overweight/obese before their pregnancy, a relatively low prevalence in comparison to published reports for the corresponding population (32, 33). This could be attributed to deliberate under-reporting, or recall bias for the self-reported pre-pregnancy anthropometric data (body weight and height) (34). Similar observations have been previously reported in Greece by Manios et al. in 2009 (35) and it is a common limitation in similar studies (36). Another limitation of the study lies in the fact that data could not be collected for year 2002, which might have affected the analysis with respect to consistency across time. Moreover, the sample of mothers included in the study did not show statistically significant levels of other risk factors related to intrauterine or foetal growth (i.e., gestational diabetes, increased blood pressure, etc.). Thus, the researchers concentrated their analysis only on the risk associated with GWG and maternal age at pregnancy. Finally, it should be mentioned that although

several characteristics related to pregnancy and gestational maternal habits were assessed (given that the main purpose of this study was to explore the effect of gestational characteristics on childhood obesity), other factors that could affect offspring's weight status, such as offspring's lifestyle habits (dietary and physical activity habits) and general health status during infancy and childhood, were not evaluated in the present study and not included as confounding factors in our analyses.

Conclusion

The present study indicated that GWG was associated with the risk of obesity at various life stages of the offspring (e.g., newborn, infant at age 2 and child at age 8). Specifically, according to our results, when a mother gains excess weight during pregnancy, the risk that her offspring will be born with excess weight and be overweight or obese during childhood increases significantly. With respect to consistency over time, our results indicate no changes in the effect of maternal age and GWG on the offspring's risk for developing overweight or obesity throughout the decade studied (1997–2007 except 2002). Our study supports previous reports and confirms the detrimental role of excess weight gain during pregnancy on childhood obesity, a fact that is already addressed in the current IOM guidelines for weight gain during pregnancy. Under this scope, health care providers should continue to encourage and support women to start their pregnancy with a BMI in the normal weight category and limit their GWG to the range specified for their pre-pregnancy BMI.

Acknowledgments

The authors want to thank the study subjects for their willingness to participate. We want to thank Dr Sarah Toombs Smith for editorial assistance. We also very grateful to Mrs Stavroula Parastatidou, Markella Symeopoulou and Mema Lampropoulou for their assistance with the data collection.

Financial Support

This study was conducted with the support of the Institute for Translational Sciences at the University of Texas Medical Branch, supported in part by a Clinical and Translational Science Award (UL1TR000071) from the National Centre for Advancing Translational Sciences, National Institutes of Health, OPAP SA – Greece, Nestlé - Greece, and support from the Harokopio University Post Graduate program on Nutrition and Dietetics.

References

1. James WP. The epidemiology of obesity: the size of the problem. *Journal of internal medicine*. 2008; 263(4):336–352. [PubMed: 18312311]
2. Kosti RI, Panagiotakos DB. The epidemic of obesity in children and adolescents in the world. *Central European journal of public health*. 2006; 14(4):151–159. [PubMed: 17243492]
3. Tambalis KD, Panagiotakos DB, Kavouras SA, Kallistratos AA, Moraiti IP, Douvis SJ, et al. Eleven-year prevalence trends of obesity in Greek children: first evidence that prevalence of obesity is leveling off. *Obesity (Silver Spring, Md)*. 2010; 18(1):161–166.
4. Ogden CL, Carroll MD, Flegal KM. High body mass index for age among US children and adolescents, 2003–2006. *Jama*. 2008; 299(20):2401–2405. [PubMed: 18505949]
5. Tambalis KD, Panagiotakos DB, Psarra G, Sidossis LS. Inverse but independent trends in obesity and fitness levels among Greek children: a time-series analysis from 1997 to 2007. *Obesity facts*. 2011; 4(2):165–174. [PubMed: 21577024]
6. Elks CE, Loos RJ, Hardy R, Wills AK, Wong A, Wareham NJ, et al. Adult obesity susceptibility variants are associated with greater childhood weight gain and a faster tempo of growth: the 1946

- British Birth Cohort Study. The American journal of clinical nutrition. 2012; 95(5):1150–1156. [PubMed: 22456663]
7. Rooney BL, Mathiason MA, Schauburger CW. Predictors of obesity in childhood, adolescence, and adulthood in a birth cohort. Maternal and child health journal. 2011; 15(8):1166–1175. [PubMed: 20927643]
 8. Mamun AA, Callaway LK, O'Callaghan MJ, Williams GM, Najman JM, Alati R, et al. Associations of maternal pre-pregnancy obesity and excess pregnancy weight gains with adverse pregnancy outcomes and length of hospital stay. BMC pregnancy and childbirth. 2011; 11:62. [PubMed: 21892967]
 9. Gaskins RB, LaGasse LL, Liu J, Shankaran S, Lester BM, Bada HS, et al. Small for gestational age and higher birth weight predict childhood obesity in preterm infants. American journal of perinatology. 2010; 27(9):721–730. [PubMed: 20408111]
 10. Arenz S, Von Kries R. Protective effect of breast-feeding against obesity in childhood: can a meta-analysis of published observational studies help to validate the hypothesis? Advances in experimental medicine and biology. 2009; 639:145–152. [PubMed: 19227541]
 11. Park S, Sappenfield WM, Bish C, Salihu H, Goodman D, Bensyl DM. Assessment of the Institute of Medicine recommendations for weight gain during pregnancy: Florida, 2004–2007. Maternal and child health journal. 2011; 15(3):289–301. [PubMed: 20306221]
 12. Medicine, Io. Subcommittee on nutritional status and weight gain during pregnancy, Weight gain during pregnancy: reexamining the guidelines. Washington, DC: National Academy Press; 2009.
 13. Cole TJ, Flegal KM, Nicholls D, Jackson AA. Body mass index cut offs to define thinness in children and adolescents: international survey. BMJ (Clinical research ed). 2007; 335(7612):194.
 14. Ebbeling CB, Pawlak DB, Ludwig DS. Childhood obesity: public-health crisis, common sense cure. Lancet. 2002; 360(9331):473–482. [PubMed: 12241736]
 15. Whitaker RC, Dietz WH. Role of the prenatal environment in the development of obesity. The Journal of pediatrics. 1998; 132(5):768–776. [PubMed: 9602184]
 16. Catalano PM. Obesity and pregnancy--the propagation of a viscous cycle? The Journal of clinical endocrinology and metabolism. 2003; 88(8):3505–3506. [PubMed: 12915626]
 17. Gaillard R, Welten M, Oddy WH, Beilin LJ, Mori TA, Jaddoe V, et al. Associations of maternal prepregnancy body mass index and gestational weight gain with cardio-metabolic risk factors in adolescent offspring: a prospective cohort study. BJOG : an international journal of obstetrics and gynaecology. 2016; 123(2):207–216. [PubMed: 26525168]
 18. Whitaker RC. Predicting preschooler obesity at birth: the role of maternal obesity in early pregnancy. Pediatrics. 2004; 114(1):e29–e36. [PubMed: 15231970]
 19. Laitinen J, Power C, Jarvelin MR. Family social class, maternal body mass index, childhood body mass index, and age at menarche as predictors of adult obesity. The American journal of clinical nutrition. 2001; 74(3):287–294. [PubMed: 11522550]
 20. Li C, Kaur H, Choi WS, Huang TT, Lee RE, Ahluwalia JS. Additive interactions of maternal prepregnancy BMI and breast-feeding on childhood overweight. Obesity research. 2005; 13(2):362–371. [PubMed: 15800295]
 21. Parsons TJ, Power C, Manor O. Fetal and early life growth and body mass index from birth to early adulthood in 1958 British cohort: longitudinal study. BMJ (Clinical research ed). 2001; 323(7325):1331–1335.
 22. Stettler N, Tershakovec AM, Zemel BS, Leonard MB, Boston RC, Katz SH, et al. Early risk factors for increased adiposity: a cohort study of African American subjects followed from birth to young adulthood. The American journal of clinical nutrition. 2000; 72(2):378–383. [PubMed: 10919930]
 23. Oken E, Taveras EM, Kleinman KP, Rich-Edwards JW, Gillman MW. Gestational weight gain and child adiposity at age 3 years. American journal of obstetrics and gynecology. 2007; 196(4):322 e1–322 e8. [PubMed: 17403405]
 24. Olson CM, Strawderman MS, Reed RG. Efficacy of an intervention to prevent excessive gestational weight gain. American journal of obstetrics and gynecology. 2004; 191(2):530–536. [PubMed: 15343232]

25. Oken E, Rifas-Shiman SL, Field AE, Frazier AL, Gillman MW. Maternal gestational weight gain and offspring weight in adolescence. *Obstetrics and gynecology*. 2008; 112(5):999–1006. [PubMed: 18978098]
26. Egan AM, Dennedy MC, Al-Ramli W, Heerey A, Avalos G, Dunne F. ATLANTIC-DIP: excessive gestational weight gain and pregnancy outcomes in women with gestational or pregestational diabetes mellitus. *The Journal of clinical endocrinology and metabolism*. 2014; 99(1):212–219. [PubMed: 24187402]
27. Chung JG, Taylor RS, Thompson JM, Anderson NH, Dekker GA, Kenny LC, et al. Gestational weight gain and adverse pregnancy outcomes in a nulliparous cohort. *European journal of obstetrics, gynecology, and reproductive biology*. 2013; 167(2):149–153.
28. Walsh JM, McGowan CA, Mahony RM, Foley ME, McAuliffe FM. Obstetric and metabolic implications of excessive gestational weight gain in pregnancy. *Obesity (Silver Spring, Md)*. 2014; 22(7):1594–1600.
29. He X, Hu C, Chen L, Wang Q, Qin F. The association between gestational weight gain and substantial weight retention 1-year postpartum. *Archives of gynecology and obstetrics*. 2014; 290(3):493–499. [PubMed: 24728106]
30. Haugen M, Brantsaeter AL, Winkvist A, Lissner L, Alexander J, Oftedal B, et al. Associations of pre-pregnancy body mass index and gestational weight gain with pregnancy outcome and postpartum weight retention: a prospective observational cohort study. *BMC pregnancy and childbirth*. 2014; 14:201. [PubMed: 24917037]
31. Alberico S, Montico M, Barresi V, Monasta L, Businelli C, Soini V, et al. The role of gestational diabetes, pre-pregnancy body mass index and gestational weight gain on the risk of newborn macrosomia: results from a prospective multicentre study. *BMC pregnancy and childbirth*. 2014; 14:23. [PubMed: 24428895]
32. Krassas GE, Kelestimur F, Micic D, Tzotzas T, Konstandinidis T, Bougoulia M, et al. Self-reported prevalence of obesity among 20,329 adults from large territories of Greece, Serbia and Turkey. *Hormones (Athens, Greece)*. 2003; 2(1):49–54.
33. Manios Y. Design and descriptive results of the "Growth, Exercise and Nutrition Epidemiological Study In preSchoolers": the GENESIS study. *BMC public health*. 2006; 6:32. [PubMed: 16480515]
34. Villanueva EV. The validity of self-reported weight in US adults: a population based cross-sectional study. *BMC public health*. 2001; 1:11. [PubMed: 11716792]
35. Manios Y, Grammatikaki E, Kondaki K, Ioannou E, Anastasiadou A, Biribilis M. The effect of maternal obesity on initiation and duration of breast-feeding in Greece: the GENESIS study. *Public health nutrition*. 2009; 12(4):517–524. [PubMed: 18547456]
36. Brawarsky P, Stotland NE, Jackson RA, Fuentes-Afflick E, Escobar GJ, Rubashkin N, et al. Pre-pregnancy and pregnancy-related factors and the risk of excessive or inadequate gestational weight gain. *International journal of gynaecology and obstetrics: the official organ of the International Federation of Gynaecology and Obstetrics*. 2005; 91(2):125–131.

Significance Statement

The study is important to the research community because it explored the potential association between GWG and the offspring's weight status at three different developmental stages (e.g., newborn, 2 and 8 years) and explored the consistency of this association across time (e.g., 1997–2007). It confirms that GWG is associated with a risk of obesity at various life stages of the offspring's studied (e.g., newborn, infant at age 2 and child at age 8). When a mother gains excess weight during pregnancy, the risk that her offspring will be born with excess weight and be overweight or obese during childhood increases significantly. In this respect, health care providers should advise women to start their pregnancy with a BMI in the normal weight category and limit their GWG to the range specified for their pre-pregnancy BMI according to IOM guidelines.

Transparency Declaration

"The lead author affirms that this manuscript is an honest, accurate, and transparent account of the study being reported, that no important aspects of the study have been omitted and that any discrepancies from the study as planned (and registered with) have been explained. The reporting of this work is compliant with CONSORT¹/STROBE²/PRISMA³ guidelines.

Table 1

Characteristics of the studied sample of mothers and their offspring (n=5,125).

Offspring characteristics	
Males, n(%)	2686 (52.4%)
Females, n(%)	2439 (47.6%)
Birth weight, kg *	3.33±0.50 (1.20–5.80)
BMI at age 2 (infant), kg/m ² *	16.5±2.28 (9.07–28.40)
BMI at age 8 (child), kg/m ² *	17.6±3.01 (10.20–46.29)
Maternal characteristics	
Maternal age at pregnancy, years	27.84 (15, 48)
Gestational weight gain (GWG), kg	14.3 (3, 45)
Relative gestational weight gain, %kg	21.7 (16.7, 29.9)
Maternal BMI Status in first visit, n (%)	
Underweight	194 (3.8%)
Normal	4,044 (78.9%)
Overweight	757 (14.8%)
Obese	130 (2.5%)
Maternal BMI status in last visit, n (%)	
Normal	1302 (25.4%)
Overweight	2467 (48.1%)
Obese	1356 (26.5%)
IOM category, n (%)	
Inadequate	1613 (31.5%)
Adequate	1747 (34.1%)
Excess	1765 (34.4%)

Data are presented as absolute and relative frequencies or median (quartiles) unless stated otherwise.

* mean (standard deviation) and range

BMI: body mass index; IOM, Institute of Medicine.

Table 2

Results from multiple linear regression models that were estimated to evaluate the association between maternal age and GWG (independent predictors) with birth weight (newborn) or BMI (dependent outcomes) at the age of 2 and 8 years.

		Predictors	b±SE	Beta	p
<i>Model 1</i>	Age 0 (newborn)	Maternal age, per 1 year	0.0001±0.002	0.001	0.929
		GWG, per 1 kg	0.008±0.001	0.098	<0.001
	Age 2	Maternal age, per 1 year	-0.042±0.012	-0.087	<0.001
		GWG, per 1 kg	0.053±0.009	0.142	<0.001
	Age 8	Maternal age, per 1 year	0.006±0.009	0.010	0.485
		GWG, per 1 kg	0.034±0.007	0.068	<0.001
<i>Model 2</i>	Age 0 (newborn)	Maternal age, per 1 year	0.001±0.002	-0.004	0.828
		IOM Category (Excess)	0.032±0.017	0.032	0.063
	Age 2	Maternal age, per 1 year	-0.045±0.014	-0.094	0.002
		IOM Category (Excess)	0.472±0.136	0.103	0.001
	Age 8	Maternal age, per 1 year	0.004±0.011	0.007	0.696
		IOM Category (Excess)	0.476±0.104	0.079	<0.001

GWG: gestational weight gain; BMI: Body mass index; SE: standard error; IOM: Institute of Medicine.