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)\textsuperscript{1–4}

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ABSTRACT

Background: Little is known about associations of gestational weight gain (GWG) with long-term maternal health.

Objective: We aimed to examine associations of prepregnancy weight and GWG with maternal body mass index (BMI; in kg/m\textsuperscript{2}), waist circumference (WC), systolic blood pressure (SBP), and diastolic blood pressure (DBP) 16 y after pregnancy.

Design: This is a prospective study in 2356 mothers from the Avon Longitudinal Study of Parents and Children (ALSPAC)—a population-based pregnancy cohort.

Results: Women with low GWG by Institute of Medicine recommendations had a lower mean BMI (−1.56; 95% CI: −2.12, −1.00) and WC (−3.37 cm; −4.91, −1.83 cm) than did women who gained weight as recommended. Women with a high GWG had a greater mean BMI (2.90; 2.27, 3.52), WC (5.84 cm; 4.15, 7.54 cm), SBP (2.87 mm Hg; 1.22, 4.52 mm Hg), and DBP (1.00 mm Hg; −0.02, 2.01 mm Hg). Analyses were adjusted for age, offspring sex, social class, parity, smoking, physical activity and diet in pregnancy, mode of delivery, and breastfeeding. Women with a high GWG had 3-fold increased odds of overweight and central adiposity. On the basis of estimates from random-effects multilevel models, prepregnancy weight was positively associated with later BMI, WC, increased odds of overweight and obesity, and central adiposity. GWG in midpregnancy (19–28 wk) was associated with later greater SBP, DBP, and central adiposity but only in women with a normal prepregnancy BMI.

Conclusions: Results support initiatives aimed at optimizing prepregnancy weight. Recommendations on optimal GWG need to balance contrasting associations with different outcomes in both mothers and offspring.

INTRODUCTION

Few studies have examined the long-term effects of gestational weight gain (GWG) on maternal health. A systematic review examining child and maternal outcomes of GWG identified 5 studies that looked at the association of GWG with long-term (≥3 y) weight retention, 4 studies of the association of GWG with interpregnancy weight retention, and 1 study of the association of GWG with premenopausal breast cancer (1). Both this systematic review (1) and the 2009 US Institute of Medicine (IOM) guidelines on GWG (2) highlight the need for further high-quality research regarding associations of GWG with long-term maternal outcomes (2). Similarly, the new National Institute for Health and Clinical Excellence (NICE) guidelines on weight management before, during, and after pregnancy note the lack of evidence on whether adhering to the IOM guidelines is associated with benefit to mothers and offspring and whether these guidelines are applicable to the United Kingdom (3).

Since publication of the aforementioned systematic review (1), Mamun et al (4) have reported a positive association of GWG with weight retention 21 y postpartum in a cohort of 2055 Australian women. That study used just 2 measurements of gestational weight and thus was unable to explore different patterns of GWG in relation to later weight retention. Further indirect evidence of an association between GWG and long-term weight gain stems from studies examining the association between parity and postpartum weight gain (5, 6). To the best of our knowledge, associations between GWG and cardiovascular disease risk factors or disease in
later life have not been studied previously but are plausible given the existing evidence (even if scant and indirect) of positive independent associations of GWG with postpartum weight retention. The aim of this study was to examine the associations of prepregnancy weight and GWG with maternal body mass index (BMI), waist circumference (WC), and blood pressure (BP) measured some 16 y after pregnancy.

SUBJECTS AND METHODS

The Avon Longitudinal Study of Parents and Children (ALSPAC) is a prospective population-based birth cohort study that recruited 14,541 pregnant women resident in Avon, United Kingdom, with expected dates of delivery between 1 April 1991 and 31 December 1992 (http://www.alspac.bris.ac.uk). There were 13,617 mother-offspring pairs from singleton live births who survived to ≥1 y of age; only singleton pregnancies are considered in this article. We further restricted the analyses to women with term deliveries (between 37 and 44 wk of gestation; n = 12,976). Ethical approval for this study was obtained from the ALSPAC Law and Ethics Committee and the Local Research Ethics Committee.

Gestational weight gain

Six trained research midwives abstracted data from obstetric medical records. No between-midwife variation in mean values of abstracted data and repeat data entry checks demonstrated error rates consistently <1%. Obstetric data abstractions included every measurement of weight entered into the medical records [median number of repeat measurements per woman: 10, interquartile range (IQR): 8, 11] and the corresponding gestational age and date.

Outcomes

From age 7 y, surviving offspring, with parental consent, were invited to regular follow-up clinics. While offspring attended the 15-y follow-up clinic (n = 5509), clinic staff measured the accompanying adult’s weight, height, and BP if time permitted. None of the accompanying biological mothers who were asked to participate declined consent. Of 4279 biological mothers who accompanied their child to the clinic, BP was measured in 3877, height and weight in 2401, and WC in 1619.

Height and weight were measured while the subjects were wearing light clothing and no shoes. Weight was measured to the nearest 0.1 kg by using Tanita scales (Tanita Europe BV, Amsterdam, Netherlands). Height was measured to the nearest 0.1 cm by using a Harpenden stadiometer (Holtain Ltd, Cymrych, United Kingdom). WC was measured to the nearest 1 mm at the midpoint between the lower ribs and the pelvic bone with a flexible tape. Seated BP was measured by using a Dinamap 9301 Vital Signs Monitor (Morton Medical, London, United Kingdom). Two readings of SBP and DBP were recorded, and the mean is used here.

Other variables

Maternal age, parity, mode of delivery (cesarean or vaginal delivery), diagnosis of diabetes, BP, and proteinuria at each antenatal visit and the child’s sex were obtained from the obstetric records. On the basis of questionnaire responses, the highest parental occupation was used to allocate the children to family social class groups [classes I (professional/managerial) to V (unskilled manual workers)] by using the 1991 British Office of Population and Census Statistics classification. Information on height, prepregnancy weight, maternal smoking in pregnancy, physical activity and diet in pregnancy, duration of breastfeeding, and current smoking was obtained from questionnaire responses. Maternal smoking in pregnancy was categorized as never smoked, smoked before pregnancy or in the first trimester and then stopped, or smoked throughout pregnancy. Physical activity in pregnancy was assessed at 18 wk of gestation, expressed in average metabolic equivalents (METs) (7) and categorized into fifths. Energy intake was assessed by using a food-frequency questionnaire at 32 wk of gestation and adjusted for underreporting as previously reported (8). Duration of breastfeeding (at 15 mo) was categorized as never, 0–3 mo, 3–5 mo, or ≥6 mo. Current smoking (assessed 12 y after pregnancy) was categorized as none, and the smokers’ distribution was divided into quartiles on the basis of number of cigarettes smoked per week. The index pregnancy was considered to be the last pregnancy if women reported no additional pregnancies by 134 mo after the index pregnancy.

Statistical analysis

Associations of GWG with outcomes were studied by using the new 2009 IOM definitions of recommended GWG (2) and serial measurements of maternal weight that allowed us to study the effect of the timing of GWG on outcomes. To allocate women to IOM categories of lower than, recommended, and higher than recommended GWG, we used weight measurements from the obstetric notes and subtracted the first from the last weight measurement in pregnancy to derive absolute weight gain. Prepregnancy BMI was based on the predicted prepregnancy weight from the multilevel models (see below) and maternal report of height. Self-reported and predicted prepregnancy weight were highly correlated (Pearson’s r = 0.92).

As previously described, all pregnancy weight measurements [median number of repeat measurements per woman: 10; interquartile range (IQR): 8, 11] were used to develop a linear spline multilevel model (with 2 levels: woman and measurement occasion) relating weight (outcome) to gestational age (exposure), with knots at 18 and 28 wk (9). The knots were placed to best reflect the observed data. Here, additional data were available compared with a previous publication examining offspring outcomes (9); hence, the difference in the placement of the knots. This multilevel model was then used to predict for each woman her weight at 0 wk gestation (referred to as “prepregnancy weight”) and GWG (per week) from 0 to 18 wk (early-pregnancy GWG), 19 to 28 wk (midpregnancy GWG), and 29 wk to delivery (late-pregnancy GWG). We scaled maternal prepregnancy weight and gestational weight change to facilitate clinical interpretation, examining the variation in outcomes per additional 1 kg of maternal weight at conception and per 400-g gain per week of gestation for GWG (the recommended rate of GWG in women with a normal prepregnancy BMI) (2).

Complete data on GWG, outcomes, and confounders were available for 1397 women for associations with later BMI, 978 women for WC, and 2200 women for BP. We compared the characteristics of women in our subsample (women with data on any of the outcomes and all confounders; n = 2,356) with women
excluded from the subsample because of either missing outcome or confounder data but for whom GWG data were available when linear or logistic regression was used as appropriate. Associations of outcomes with the IOM categories and with the individual estimates of maternal prepregnancy weight and early-, mid-, and late-pregnancy GWG, estimated from the multilevel models, were undertaken by using linear and logistic regression. In the basic model we adjusted for the potential confounders age at outcome measurement and offspring sex. For the multilevel model exposures only, we adjusted for prepregnancy weight and GWG in previous periods in a second model. In the fully adjusted model, we also adjusted for the following potential confounders: parity, pregnancy, smoking, total caloric intake, physical activity, social class, and current smoking (via its association with prepregnancy smoking status), mode of delivery, and duration of breastfeeding as a potential mediator. In models using IOM categories, we also adjusted for prepregnancy BMI and gestational age (this is taken account of in the multilevel models). We also examined whether there were interactions between GWG and being normal weight (BMI < 25) or overweight/obese during prepregnancy (BMI ≥ 25) (10). For our main analyses, we examined BMI and WC after pregnancy as continuously measured variables. We also examined binary outcomes of overweight/obesity and central adiposity (WC ≥ 80 cm) (11). Associations of absolute GWG with outcomes were tested for linearity by using models with fractional polynomials.

Sensitivity analyses
We repeated the analyses including only women for whom the index pregnancy was their last (n = 966). We also repeated the analyses excluding women who did not gain weight during pregnancy (n = 7) and women who gained ≥30 kg (n = 3), because these values may indicate an underlying pathology, and excluding women with diabetes (n = 23) and preeclampsia (n = 43).

Missing data
We used multivariate multiple imputation to impute missing variables (mostly outcome data) for participants with measures of weight in pregnancy (n = 12,447), including all exposures, covariates, outcomes, and potential predictors of missing data in the imputation equations (see online supplement) (12). The multiple multivariate imputation approach creates many copies of the data (in this case, 30 copies), each of which has missing values imputed, with an appropriate level of randomness, by chained equations. We repeated the analyses using the multiple imputation data sets. The results were obtained by averaging estimates across the 30 imputed data sets by using Rubin’s rules, and the procedure takes into account uncertainty in the imputation (12). All analyses were conducted by using Stata version 11.0 (StataCorp, College Station, TX).

RESULTS
GWG measured in the study cohort was compared with the 2009 IOM recommendations (Table 1). In our cohort, women who were underweight before pregnancy and women with normal prepregnancy BMI had a mean GWG within the recommended range, whereas overweight and obese women gained more than recommended on average (Table 1). Women with less than the recommended GWG (n = 825), the recommended GWG (n = 957), and higher than the recommended GWG (n = 574) had mean weight gains of 8.4 (range: −6.9 to 12.4), 13.1 (5.0–18.0), and 17.7 (9.1–33.5) kg, respectively. Other characteristics according to IOM categories are presented in Table 2.

The mean difference in BMI, WC, SBP, and DBP and the risk of overweight/obesity and central adiposity 16 y after the index pregnancy are shown in Table 3 by IOM categories of GWG. Women with lower than recommended GWG had lower BMI, WC, lower WC, and a reduced risk of overweight/obesity than did women with recommended GWG in both age and offspring sex and in fully adjusted models. Conversely, women who gained more than recommended had a higher mean BMI, WC, SBP, and DBP and a greater risk of overweight/obesity and central adiposity than did women with the recommended GWG. The odds of overweight/obesity and central adiposity in women with higher than recommended GWG were 3 times those in women who gained as recommended.

In Table 4, associations of prepregnancy weight and GWG with outcomes are examined by using the estimates from the multilevel models. Interactions between being overweight/obese (BMI ≥ 25) before pregnancy and GWG were noted for mid-pregnancy (weeks 19–28) GWG in relation to BMI, SBP, DBP, and central adiposity and between being overweight/obese before pregnancy and GWG in late pregnancy (weeks ≥29) in relation to DBP and WC. Hence, results stratified by whether women were normal or overweight/obese before pregnancy are presented for these associations.

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**Table 1**
Institute of Medicine (IOM)–recommended levels of gestational weight gain according to prepregnancy BMI categories and observed levels in the study cohort

| Prepregnancy BMI (in kg/m²) | IOM recommendations | Mean rate of weight gain in second and third trimesters | ALSPAC | Mean (±SD) weight gain in mid- and late pregnancy (≥18 wk) |
|----------------------------|---------------------|-------------------------------------------------------|--------|--------------------------------------------------|
|                            | Range of absolute weight gain | Mean (range) absolute weight gain | Mean (±SD) weight gain in mid- and late pregnancy (≥18 wk) |
| Underweight, <18.5         | 12.5–18             | 0.51 | 12.7 (3.0–27.5) [267] | 0.46 (0.14) [267] |
| Normal weight, 18.5–24.9   | 11.5–16             | 0.42 | 12.9 (−0.2 to 26.6) [1701] | 0.47 (0.13) [1701] |
| Overweight, 25–29.9        | 7–11.5              | 0.28 | 11.9 (−2.2 to 33.5) [294] | 0.45 (0.16) [294] |
| Obese, ≥30                | 5–9                 | 0.22 | 10.1 (−6.9 to 30.9) [94] | 0.39 (0.20) [94] |

1 n in brackets. ALSPAC, Avon Longitudinal Study of Parents and Children.
Prepregnancy weight was positively associated with all outcomes in both the age- and offspring sex–adjusted model (model 1) and in the fully adjusted model (model 3). GWG in all periods of gestation was positively associated with BMI; however, in midpregnancy (19–28 wk gestation), this association was only present in normal-weight women. GWG in all periods of gestation was positively associated with WC when adjusted for potential confounders and mediators. With the exception of a positive association of GWG in midpregnancy (19–28 wk) with BP in women who were normal weight, no strong evidence indicated that GWG in any time period was associated with SBP or DBP. GWG in all 3 periods of gestation was associated with greater odds of overweight/obesity and central adiposity, although the association of midpregnancy GWG with central adiposity was only apparent in women with normal weight. A stronger association of GWG in late pregnancy (≥29 wk) with central adiposity was observed in women who were overweight/obese before pregnancy than in women with a normal prepregnancy BMI. We found no strong evidence (all \( P \geq 0.05 \) for the linear compared with the best-fitting nonlinear model) for nonlinearity of associations of GWG with outcomes.

The results were minimally changed when women with diabetes and women with preeclampsia were excluded from the analyses, when women with extreme GWG values (≤0 and >30 kg) were excluded, or when the analyses were limited to women for whom the index pregnancy was the last (results available from authors on request).

A comparison of the subgroup of women included in our analyses with those who were excluded, mainly because of missing outcome data, and the differences between the 2 groups are shown elsewhere (see Supplemental Table 2 under “Supplemental data” in the online issue). However, the distributions of BMI, WC, SBP, and DBP in our subsample and in the imputed data sets were very similar (see Supplemental Table 2 under “Supplemental data” in the online issue). Moreover, when we repeated the analyses using the imputed data sets (see Supplemental Tables 3 and 4 under “Supplemental data” in the online issue), the results were essentially the same as those presented here, except for one difference. In overweight women, we found a strong (odds ratio: 4.70; 95% CI: 2.60, 8.50) association between GWG in midpregnancy and central adiposity in model 3, which was not noted in the complete case analysis.

**DISCUSSION**

In this contemporary cohort, we have shown that women with lower than recommended GWG (according to the 2009 IOM guidelines) had a lower mean BMI and WC, 16 y after the index pregnancy, than did women who gained as recommended. However, women with a higher than recommended GWG had a greater mean BMI and WC and a higher mean SBP and DBP than did women with the recommended GWG after adjustment for potential confounders. In more detailed analyses, we found positive associations of prepregnancy weight with all outcomes and that GWG in early and late pregnancy were positively associated with overweight/obesity and central adiposity, and mid-pregnancy GWG was positively associated with overweight/obesity, central adiposity, SBP, and DBP in women who were normal weight before pregnancy.

Two previous studies examined the association between GWG using IOM categories and weight (13)/BMI (14) 15 y after pregnancy and another with BMI 21 y after pregnancy (4). Similarly to our results, all studies found that women with higher than recommended GWG [by 1990 IOM categories (13, 14) and 2009 IOM categories (4)] subsequently had a higher BMI/weight than did women who gained as recommended. Conversely, and similarly to...
us, 2 studies (13, 14) found that women with a lower than recommended GWG had lower BMI/weight 15 y after pregnancy than did women with the recommended GWG. No strong evidence of this was found by Mamun et al (4) for BMI measured 21 y after pregnancy. None of these studies had the detailed repeat measurements of gestational weight that we were able to examine in our study, and none examined associations with postpregnancy WC or BP.

Because the IOM criteria combine prepregnancy BMI and GWG and recommend lower levels of weight gain in women who are already overweight or obese before pregnancy, it is possible that the associations of IOM categories with outcomes are driven by either prepregnancy BMI or GWG. In particular, the category of higher than recommended GWG may include more women who are overweight or obese before pregnancy because these have a lower threshold to reach to enter this category. In our study, more overweight women were indeed classified as having a higher than recommended GWG than were normal-weight women (51% compared with 19%); however, in detailed analyses (Table 4) there were positive associations of GWG in mid-pregnancy with some outcomes only in women with a normal prepregnancy weight, which existed after adjustment for prepregnancy weight. Hence, GWG is associated with outcomes in addition to prepregnancy weight.

Several potentially non-mutually exclusive mechanisms could explain our findings. First, they could reflect the tracking in individual size across the life course, with greater BMI associated with a susceptibility to greater GWG. However, prepregnancy BMI is inversely associated with GWG (2), and we found evidence of independent associations of prepregnancy weight and GWG with outcomes in later life. Alternatively, women with greater prepregnancy BMI may continue to engage in lifestyles (high-energy diet and low levels of physical activity) during and/or after their pregnancy that promote greater GWG and higher BMI and WC in the longer term. However, we did adjust for caloric intake and physical activity in pregnancy in our analyses. Our finding that GWG in midpregnancy was more detrimental to women who were not overweight before pregnancy was perhaps counterintuitive because thinner women are “allowed” to gain more weight during pregnancy than are heavier women according to IOM recommendations. However, this GWG may reflect greater maternal fat accretion: several (15–17), although not all (18), studies have shown inverse associations between gestational fat accretion and maternal prepregnancy obesity. Therefore, GWG by women who were overweight before pregnancy may be easier to lose. Consistent with this, in a prospective study of 405 Brazilian women, each 1-unit greater prepregnancy BMI was associated with a 0.5-kg lower weight retention at 9 mo postpartum (15).

### TABLE 3
Mean differences (and 95% CIs) in BMI, waist circumference (WC), and blood pressure and the risk (odds ratios and 95% CIs) of overweight and central adiposity in mothers 16 y after pregnancy by Institute of Medicine (IOM) categories of gestational weight gain.

| Outcome and IOM category | No. of subjects | Model 1 | Model 2 |
|--------------------------|-----------------|---------|---------|
| BMI (kg/m²)              |                 |         |         |
| Low                      | 1397            | -1.50 (-2.07, -0.93) | -1.56 (-2.12, -1.00) |
| Recommended              | Reference       | Reference |
| High                     | 3.19 (2.54, 3.83) | 2.90 (2.27, 3.52) |
| WC (cm)                  | 978             | -3.02 (-4.56, -1.48) | -3.37 (-4.91, -1.83) |
| Low                      | Reference       | Reference |
| Recommended              | 6.26 (4.54, 7.98) | 5.84 (4.15, 7.54) |
| High                     | 1.01 (-2.49, 0.47) | -0.94 (-2.42, 0.22) |
| SBP (mm Hg)              | 2200            |          |         |
| Low                      | Reference       | Reference |
| Recommended              | 3.32 (1.67, 4.96) | 2.87 (1.22, 4.52) |
| High                     | 0.50 (-1.41, 0.40) | -0.47 (-1.38, 0.45) |
| DBP (mm Hg)              | 2200            |          |         |
| Low                      | Reference       | Reference |
| Recommended              | 1.21 (0.21, 2.22) | 1.00 (-0.02, 2.01) |
| Overweight, BMI ≥ 25 kg/m²| 1397            | 0.56 (0.44, 0.72) | 0.54 (0.41, 0.70) |
| Low                      | Reference       | Reference |
| Recommended              | 3.67 (2.70, 4.99) | 3.58 (2.61, 4.93) |
| High                     | 0.69 (0.51, 0.92) | 0.65 (0.47, 0.88) |
| Central adiposity, WC ≥ 80 cm | 978            |          |         |
| Low                      | Reference       | Reference |
| Recommended              | 2.64 (1.79, 3.90) | 2.67 (1.78, 4.01) |

1. The results were obtained from linear or logistic regression models. SBP, systolic blood pressure; DBP, diastolic blood pressure.
2. Adjusted for maternal age at outcome assessment, gestational age, and offspring sex.
3. Adjusted for maternal age at outcome assessment, gestational age, offspring sex, head of household, social class, parity, smoking, energy intake and physical activity in pregnancy, mode of delivery, duration of breastfeeding, and current smoking.
4. Values are odds ratios (95% CIs); the reference (null) is 1, with values >1 indicating a greater risk and values <1 indicating a reduced risk.
| TABLE 4 |
| Mean differences (and 95% CIs) in BMI, waist circumference (WC), and blood pressure and the risk (odds ratios and 95% CIs) of obesity in mothers 16 y after pregnancy by prepregnancy weight and gestational weight gain (GWG) with results stratified by prepregnancy BMI

| No. of subjects | Prepregnancy weight (per 1-kg difference) | GWG 0-18 wk (per 400-g/wk change) | Prepregnancy BMI < 25 kg/m² | Prepregnancy BMI ≥ 25 kg/m² | Prepregnancy BMI < 25 kg/m² | Prepregnancy BMI ≥ 25 kg/m² |
|----------------|------------------------------------------|-----------------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| BMI (kg/m²) | | | | | | |
| Model 1 | 1397 | 0.34 (0.33, 0.36) | -2.02 (−3.64, −0.39) | 2.21 (1.66, 2.76) | -0.95 (−2.63, 0.73) | 1.97 (1.42, 2.53) |
| Model 2 | | 1.36 (0.88, 1.83) | 1.50 (0.98, 2.02) | -0.50 (−2.03, 1.04) | 0.82 (0.29, 1.34) |
| Model 3 | | 1.38 (0.91, 1.86) | 1.51 (0.98, 2.04) | -0.40 (−2.05, 1.25) | 0.91 (0.39, 1.43) |
| P for interaction | | | 0.28 | | 0.001 | |
| Waist circumference (cm) | 978 | 0.73 (0.68, 0.79) | -1.54 (−6.09, 3.01) | 3.33 (1.55, 5.10) | 4.77 (3.32, 6.21) |
| Model 1 | | 3.93 (2.51, 5.34) | 3.50 (2.02, 4.99) | 1.76 (0.34, 3.19) |
| Model 2 | | 3.82 (2.39, 5.24) | 3.59 (2.09, 5.10) | 1.99 (0.54, 3.43) |
| Model 3 | | | | |
| P for interaction | | | 0.92 | | 0.26 | 0.30 |
| SBP (mm Hg) | 2200 | 0.36 (0.30, 0.42) | -3.65 (−7.54, 0.24) | 3.11 (1.34, 4.88) | -3.15 (−6.93, 0.63) | 2.13 (0.78, 3.48) |
| Model 1 | | 0.73 (0.68, 0.79) | -1.54 (−6.09, 3.01) | 3.33 (1.55, 5.10) | 4.77 (3.32, 6.21) |
| Model 2 | | 3.93 (2.51, 5.34) | 3.50 (2.02, 4.99) | 1.76 (0.34, 3.19) |
| Model 3 | | 3.82 (2.39, 5.24) | 3.59 (2.09, 5.10) | 1.99 (0.54, 3.43) |
| P for interaction | | | 0.92 | | 0.26 | 0.30 |
| DBP (mm Hg) | 2200 | 0.16 (0.12, 0.19) | -1.95 (−4.33, 0.42) | 1.88 (0.77, 2.99) | -2.68 (−4.83, −0.53) | 1.63 (0.69, 2.58) |
| Model 1 | | 0.18 (0.17, 0.19) | -1.95 (−4.33, 0.42) | 1.88 (0.77, 2.99) | -2.68 (−4.83, −0.53) | 1.63 (0.69, 2.58) |
| Model 2 | | 0.15 (0.11, 0.18) | -1.95 (−4.33, 0.42) | 1.88 (0.77, 2.99) | -2.68 (−4.83, −0.53) | 1.63 (0.69, 2.58) |
| P for interaction | | | 0.81 | | 0.02 | |
| Overweight/obesity, BMI ≥ 25 kg/m² | 1397 | 1.17 (1.15, 1.20) | 0.96 (0.74, 1.25) | 1.84 (1.41, 2.42) | 2.33 (1.84, 2.96) |
| Model 1 | 1.17 (1.15, 1.20) | 0.96 (0.74, 1.25) | 1.84 (1.41, 2.42) | 2.33 (1.84, 2.96) |
| Model 2 | 2.30 (1.65, 3.20) | 2.32 (1.63, 3.32) | 1.48 (1.02, 2.14) |
| Model 3 | 2.27 (1.65, 3.20) | 2.31 (1.60, 3.36) | 1.57 (1.07, 2.31) |
| P for interaction | | | 0.35 | | | 0.08 |
| Central adiposity, WC ≥ 80 cm | 978 | 1.17 (1.14, 1.20) | 1.01 (0.72, 1.41) | 2.19 (1.51, 3.18) | 0.47 (0.08, 2.66) | 2.35 (1.70, 3.23) |
| Model 1 | 1.17 (1.14, 1.20) | 1.01 (0.72, 1.41) | 2.19 (1.51, 3.18) | 0.47 (0.08, 2.66) | 2.35 (1.70, 3.23) | 0.96 (0.28, 3.28) |
| Model 2 | 1.95 (1.29, 2.94) | 1.74 (1.12, 2.71) | 0.21 (0.03, 1.67) |
| Model 3 | 1.92 (1.25, 2.94) | 1.91 (1.20, 3.04) | 0.01 (0.00, 8.35) |
| P for interaction | | | 0.58 | | | 0.04 |

1 The results were obtained from linear or logistic regression models. SBP, systolic blood pressure; DBP, diastolic blood pressure.
2 A 400-g/wk change is the recommended rate of GWG in women with a normal prepregnancy BMI.
3 Adjusted for maternal age at outcome assessment and offspring sex.
4 Adjusted for maternal age at outcome assessment, offspring sex, prepregnancy weight, and GWG in previous exposure periods.
5 Adjusted for maternal age at outcome assessment, offspring sex, prepregnancy weight, GWG in previous exposure periods, head of household, social class, parity, smoking, energy intake and physical activity in pregnancy, mode of delivery, duration of breastfeeding, and current smoking.
6 Values are odds ratios (95% CIs); the reference (null) is 1, with values >1 indicating a greater risk and values <1 indicating a reduced risk.
The availability of repeat measurements of weight in pregnancy allowed us to examine associations of GWG with outcomes in 3 different periods of gestation. Our results suggest that the strongest and most consistent associations of GWG with outcomes are in early and midpregnancy (0–28 wk). This may reflect that the maternal component of GWG is largely complete by 28 wk (19, 20).

Our observed differences in GWG associations with later adiposity by prepregnancy overweight/obesity may reflect deposition and persistence of differential fat depots between normal and overweight women, because analyses of skinfold thicknesses have shown that obese women put on more fat in the upper body compartment, but that lean women put on more fat in the lower body compartment (17, 21, 22).

This study, which incorporated repeat measurements during pregnancy, allowed detailed temporal analysis of the long-term associations of GWG with several cardiovascular disease risk factors. The main limitation was that we used an opportunistic subsample that differed from women not included in the analyses (see Supplemental Table 1 under “Supplemental data” in the online issue). However, there is no reason to believe that associations would be different between these 2 groups or that whether women were included in the sample or not (ie, accompanied their child to the clinic or not) was related to their outcome measures. Moreover, results using imputed data sets were substantially the same as those presented here. Prepregnancy height was self-reported, and prepregnancy weight was estimated from models of weight gain during pregnancy; however, predicted and self-reported weight were highly correlated. We are unable to identify the separate maternal and fetal contributions to overall GWG, but our ability to divide GWG into 3 separate periods of gestation helped with the interpretation of our findings. Moreover, it would have been advantageous to have more detailed repeat measurements of postnatal weight in these women to assess whether the observed association of GWG with BMI later in life is due to weight gained later in life or to GWG never being lost. Unfortunately, such data are unavailable here and to the best of our knowledge in any other study. Because of sample size limitations, we grouped obese and overweight women into one category. However, sensitivity analyses showed that results for this group were not driven solely by the obese women. Finally, we did not have data on GWG and other pregnancy characteristics of subsequent pregnancies occurring between the index used here and the outcome assessment. Yet, results were essentially the same when we restricted our analyses only to the subgroup of women for whom this was their last pregnancy.

In summary, our finding that greater prepregnancy weight is associated with greater adiposity and higher BP 16 y after pregnancy, together with our recent findings from this cohort of increased obesity and cardiovascular disease risk factors in the offspring of women who had greater prepregnancy weight (9), support initiatives aimed at optimizing prepregnancy weight. If associations of higher than recommended GWG with long-term maternal and offspring health (9) are replicated in further studies, regular monitoring of weight in pregnancy in the United Kingdom may need to be reconsidered because it may provide a window of opportunity to intervene to prevent adverse health outcomes later in life. That said, whereas lower GWG may be beneficial for some outcomes, it is detrimental to others, particularly in offspring (2).

Hence, it is important to recognize that identifying an ideal GWG has to reflect these competing risks.

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The authors’ responsibilities were as follows—AF and DAL: conceived and designed the study; AF, KT, and DAL: had full access to all of the data in the study and jointly take responsibility for its integrity; and AF, KT, RH, and CM-W: conducted the analysis. All authors contributed to data interpretation and the draft and revision of the manuscript and provided final approval of the version to be published. None of the authors declared a conflict of interest.

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