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Epidemiology

Pregnancy weight gain by gestational age and stillbirth: a population-based cohort study

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Objective To study the association between total and early pregnancy (<22 completed weeks) weight gain and risk of stillbirth, stratified by early-pregnancy body mass index (BMI).

Design Population-based cohort study.

Setting Stockholm-Gotland Region, Sweden.

Population Pregnant women with singleton births (n = 160 560).

Methods Pregnancy weight gain was standardised into gestational age-specific z-scores. For analyses of total pregnancy weight gain, a matched design with an incidence density sampling approach was used. Findings were also contrasted with current Institute of Medicine (IOM) weight gain recommendations.

Main outcome measures Stillbirth defined as fetal death at ≥22 completed weeks of gestation.

Results For all BMI categories, there was no statistical association between total or early pregnancy weight gain and stillbirth within the range of a weight gain z-score of −2.0 SD to +2.0 SD. Among normal-weight women, the adjusted odds ratio of stillbirth for lower (−2.0 to −1.0 SD) and higher (+1.0 to +1.9 SD) total weight gain was 0.85 (95% CI; 0.48–1.49) and 1.03 (0.60–1.77), respectively, as compared with the reference category. Further, there were no associations between total or early pregnancy weight gain and stillbirth within the range of weight gain currently recommended by the IOM. For the majority of the BMI categories, the point estimates at the extremes of weight gain values (<−2.0SD and ≥2.0 SD) suggested protective effects of low weight gain and increased risks of high weight gain, but estimates were imprecise and not statistically significant.

Conclusion We found no associations between total or early pregnancy weight gain and stillbirth across the range of weight gain experienced by most women.

Keywords early-pregnancy BMI, pregnancy weight gain, stillbirth, z-scores.

Tweetable abstract There was no association between weight gain during pregnancy and stillbirth among most women.

Linked article This article is commented on by AM Siega-Riz and D Dudley, p. 982 in this issue. To view this mini commentary visit https://doi.org/10.1111/1471-0528.15112.

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Introduction

In 2015, 2.6 million pregnancies ended in a late gestation stillbirth (>28 weeks).[1] The majority of stillbirths are experienced by women in low- and middle-income countries, but many occur in high-income countries, with an average stillbirth rate of 3.5 per 1000 births.[2] Established modifiable risk factors for stillbirth include high maternal age,[3] obesity in early pregnancy,[3,4] and high interpregnancy weight gain.[5]

Gestational weight gain may be an additional modifiable risk factor for stillbirth, but evidence to confirm or refute this association is scarce. The most recent Institute of Medicine (IOM) guidelines committee on pregnancy weight gain concluded that studies on the association between weight gain and stillbirth were few in number and prone to methodological limitations.[6] This lack of evidence may be due in part to the challenges of studying pregnancy weight gain and stillbirth. First, stillbirth is a rare outcome, and large samples are required to estimate associations with reasonable statistical precision.[7] However, gestational weight gain has not been

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routinely available in national registers/databases (such as the Swedish Medical Birth Register) until recently, creating challenges in identifying sufficiently large cohorts.[8] Second, since both weight gain during pregnancy and stillbirth are correlated with gestational duration (i.e. a shorter pregnancy duration offers less opportunity to gain weight, and stillbirth is often associated with a shorter pregnancy duration than live birth), it is hard to disentangle the effects of pregnancy weight gain from the effects of gestational duration.[9] Finally, there is interest in examining the role of weight gain during early pregnancy, which has been found to be as important as late weight gain for certain pregnancy outcomes such as gestational diabetes.[10,11]

Using antenatal electronic medical records, including serial antenatal gestational weight gain measurements and new normative charts of pregnancy weight gain for gestational age,[12] we aimed to assess the association between total and early gestational weight gain z-score and the risk of stillbirth for different BMI categories in a large, population-based cohort of Swedish women.

Methods

Study population

This population-based cohort study included singleton pregnancies in the Swedish counties of Stockholm and Gotland from July 1 2008 to October 31 2014. Electronic medical record entries from all prenatal clinic visits, delivery admissions, and post-partum admissions in these counties are forwarded daily to the Stockholm–Gotland Obstetrical database.[13] All clinics consented to medical record access, and our study was approved by the regional ethics committee at Karolinska Institutet, Stockholm, Sweden (DNR: 2013/792-32: approved April 30 2013). Pregnancy terminations were excluded, while infants with congenital anomalies were included.

Pregnancies of women without measured weight in early pregnancy [<14 completed weeks (i.e., 14 weeks, 0 days)], an implausible early pregnancy weight (<30 kg or >350 kg) or no available pregnancy weight-gain measurements, as well as implausible gestational weight-gain measurements (z-score <−4.0 SD or >+4.0 SD) were excluded.

Outcome

Stillbirth was defined as fetal death at ≥22 completed weeks of gestation.

Weight measurements

Early pregnancy body mass index (BMI; kg/m^2) was calculated using maternal self-reported height (cm) and the first measured weight in early pregnancy (kg). BMI was categorised as underweight (<18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), overweight (25–29.9 kg/m^2), and obese (≥30 kg/m^2).[14]

We examined total pregnancy weight gain (last measured weight minus first measured weight <14 weeks, in kg) and weight gain in early pregnancy (last measured weight prior to 22 weeks minus first measured weight <14 weeks, in kg). Early pregnancy weight gain was based on the gestational age threshold for stillbirth and corresponds approximately to the start of the periviable period.

Gestational weight gain was standardised for gestational duration using BMI-specific pregnancy weight-gain-for-gestational-age charts for Swedish women.[12] The means and standard deviations of weight gain for each week of gestation on the charts were used to convert the women' observed weight gain (in kg) into gestational-age-standardised weight gain z-scores. Weight gain z-scores were examined as a continuous variable and categorised as <−2.0, −2.0 to −1.0, −0.9 to +0.9, +1 to +1.9, and ≥+2.0.

Our analyses for total pregnancy weight gain were restricted to stillbirths in which a pregnancy weight gain measurement was available within 31 days of delivery. We then used an incidence density sampling approach to identify four controls for each stillbirth from the cohort of ongoing pregnancies at the gestational age of the stillbirth. In this design, pregnancies that subsequently ended in stillbirth were eligible to serve as controls for earlier stillbirths, providing they had vital signs of life at the time of the earlier case's delivery.[15] We used this matched design because the gestational age distribution of the last weight measurement for women with a pregnancy ending in stillbirth differed markedly from that of women with live births. That is, women with livebirths were more likely to have had a last weight measurement very close to 40 weeks, while women with a stillbirth were more likely to have had a last weight measurement much earlier in gestation. Further, we hypothesised that the interval between last weight and delivery may also differ between women with a stillbirth and women with live births because the frequency of antenatal weight visits increases as pregnancy progresses, and many stillbirths occur earlier in pregnancy.

Controls were selected such that the gestational age of their last measured weight prior to the index time (gestational age of the stillbirth) most closely matched the gestational age of the last measured weight of the stillbirth case. The weight gain measurements of the potential controls were restricted to within a 14 day (±) window of the last weight measurement of the case, selecting the weight gain measurement of the control that had the closest interval to the interval of the case within this window. For example, if the stillbirth was delivered at 250 days, with a last measured weight at 230 days, we identified each control's last measured weight that was closest to 230 days. Sampling was done separately by early pregnancy BMI category.

Covariates

Prepregnancy hypertension was identified using *International Classification of Diseases, 10th revision* diagnostic codes (ICD-10 codes I10-15, O10 or chronic hypertension from the electronic medical record). Prepregnancy diabetes was identified via ICD-10 codes (O24.0–O24.3, E10–E14). Early pregnancy smoking status was categorised at the first antenatal care visit as non-smoker, smoking 1–9 cigarettes/day, or ≥10 cigarettes/day. We obtained data on living with partner (yes/no).

Statistical analysis

The association between total gestational weight gain z-scores and stillbirth was estimated using conditional logistic regression, conditioned on the matching set, while the association between early pregnancy weight gain and stillbirth was examined using unconditional logistic regression. Weight gain z-score as a continuous variable was modelled as a linear term and restricted cubic splines, with the best fit selected based on the Akaike information criterion. All analyses were stratified by early pregnancy BMI-categories (normal weight, overweight, and obese). Underweight women were not included owing to the small number of stillbirths in this group. Adjustments were made for maternal age, height, early pregnancy BMI (to account for residual confounding within BMI categories), parity, smoking, living with partner, prepregnancy hypertension, and diabetes. We did not control for gestational diabetes or pre-eclampsia as we hypothesised that these might be downstream consequences of gestational weight gain. As recommended, we did not adjust for past obstetrical history (e.g. past stillbirth) because adjustment for factors caused in part by an exposure will introduce bias.[16–18]

For ease of interpretation, weight gain z-scores were converted back to a total weight gain in kilograms at weeks 22 and 40 based on our previously-published weight-gain-for-gestational-age z-score charts for Swedish women (see Appendix S1 for details).

Marginal estimates from our crude and adjusted regression models in which weight gain was modelled as a continuous variable were used to estimate the odds ratios for stillbirth at 0.5 increments of weight gain z-score in relation to a weight gain z-score of 0 (i.e., the 50th percentile).

As the current IOM pregnancy weight gain recommendations were established in the absence of rigorous data on the optimal weight gain ranges for reducing stillbirth, we compared the risks of stillbirth across the weight gain continuum estimated in our study to the ranges of weight gain during pregnancy recommended by the IOM.[6] The z-scores corresponding to the IOM recommendations at week 40 were calculated for each BMI category (11.5–16 kg in normal-weight women, 7–11.5 kg in overweight women, and 5–9 kg in obese women).

Results

Study population

The Obstetrix database contained the medical records of 174 524 singleton pregnancies from July 1 2008 to October 31 2014. Excluding 13 964 women missing early pregnancy weight measurements (<14 + 0 weeks), implausible early pregnancy weight, or lack of plausible weight gain data, left 160 560 pregnancies (see Figure S1 for flow chart). As shown in Table S1, excluded women were approximately 1 year younger, less likely to be living with a partner, and more likely to smoke than women included in our study. The rate of stillbirth was approximately 20% higher (3.8 per 1000 in excluded versus 3.1 per 1000 in included women). However, last weight prior to delivery was similar (78.5 kg among n = 13 324 women excluded because of missing early pregnancy BMI versus 77.3 kg among women included in our final cohort).

In this cohort, there were 505 stillbirths (3.1 per 1000), of which 315 had a weight measurement within 31 days of delivery; of these, 91.4% (288 of 315) were antepartum stillbirths and 8.6% (27 of 315) intrapartum stillbirths. Nearly eighteen percent (17.8%) of the stillbirths occurred after <28 weeks gestation, 14.3% at 28–33 weeks, 15.2% at 34–36 weeks, 42.9% at 37–40 weeks, and 9.8% at ≥41 weeks. Our analysis of total weight gain included 303 stillbirths with 1211 controls (12 stillbirths to underweight women were not analysed owing to low numbers). Early pregnancy weight gain was available for 59 523 women with a BMI ≥ 18.5, including 187 stillbirths.

Study characteristics

Stillbirths that were excluded from our analyses of total weight gain because they did not have a gestational weight gain measurement within 31 days of delivery (n = 190) were more likely to be born to older women (33 versus 31 years) and to have a younger gestational age at delivery than included stillbirths (213 versus 246 days). This gestational age difference explained the lower number of weight measurements among excluded stillbirth, and the lower total gestational weight gain (3.8 versus 11 kg; Table 1).

As compared with live births, stillbirths included in our analyses were more likely to be delivered at a younger gestational age (279 versus 246 days), which is reflected the lower total gestational weight gain of stillbirths compared with live births. However, after standardising for gestational age, pregnancy weight gain z-scores were comparable. Mothers of stillbirths were more likely to be overweight and obese, to smoke, to be nulliparous, and to have prepregnancy diabetes or hypertension (Table 1).

Total and early weight gain during pregnancy

Normal weight

In normal-weight women, pregnancy weight gain above (+1.0 SD to +1.9 SD) or below (−2.0 SD to −1.0 SD)

Table 1. Maternal and pregnancy characteristics among 160 560 pregnancies in the Stockholm–Gotland region of Sweden between 2008 and 2014, showing live-births and included and excluded stillbirths

Characteristic	Live births (*n* = 160 055)	Stillbirths included (*n* = 315)	Stillbirths excluded (*n* = 190)
Gestational weight gain*			
Kg, mean ± SD	12.4 ± 5.5	11.0 ± 5.4	3.8 ± 4.8
z-score, mean ± SD	0.014 ± 0.95	0.054 ± 1.00	−0.057 ± 0.80
Gestational age, mean ± SD	279 ± 12.0	246 ± 41.2	213 ± 44.8
No. of weight measurements, median (IQR)	5 (3–7)	4 (3–6)	2 (1–2)
BMI in early pregnancy, kg/m^2, no. (%)			
Underweight (<18.5)	4799 (3.0%)	12 (3.8%)	2 (1.0%)
Normal weight (18.5–24.9)	107 239 (67.0%)	164 (52.1%)	97 (51.0%)
Overweight (25.0–29.9)	34 230 (21.4%)	94 (29.8%)	65 (34.2%)
Obese class I (30.0–34.9)	10 160 (6.4%)	33 (10.5%)	18 (9.4%)
Obese class II (35.0–39.9)	2762 (1.7%)	10 (3.2%)	6 (3.2%)
Obese class III (≥40.0)	865 (0.5%)	2 (0.6%)	2 (1.0%)
Maternal age, yrs, mean ± SD	31.6 ± 5.0	31.6 ± 5.3	33.0 ± 5.0
Maternal height, cm, mean ± SD	166.4 ± 6.5	165.4 ± 7.1	165.6 ± 6.6
Living with partner, no. (%)	149 676 (93.5%)	285 (90.2%)	168 (88.4%)
Nulliparous, no. (%)	73 535 (46.0%)	158 (50.2%)	91 (47.9%)
Prepregnancy hypertension, no. (%)	1418 (0.9%)	4 (1.3%)	4 (2.1%)
Prepregnancy diabetes, no. (%)	899 (0.6%)	8 (2.5%)	2 (1.0%)
Early smoking status, no. (%)			
Nonsmoker	152 449 (95.2%)	284 (90.2%)	175 (92.2%)
1–9 cig/d	5180 (3.2%)	20 (6.3%)	11 (5.7%)
≥10 cig/d	1241 (0.8%)	7 (2.2%)	3 (1.6%)
Missing	1185 (0.7%)	4 (1.3%)	1 (0.5%)

*Based on last measurement before delivery.

average (−0.99 SD to +0.99 SD) was not associated with an increased risk of stillbirth [adjusted odds ratio (aOR) 1.03; 95% CI 0.60–1.77 and aOR 0.85; 95% CI 0.48–1.49, respectively; Table 2]. These categories reflected the weight gains experienced by 97.7% of women in our cohort.

At the extremes of weight gain values (<−2.0 SD and ≥2.0 SD), the point estimates suggested protective effects of low weight gain (aOR 0.58; 95% CI 0.13–2.63) and increased risks of high weight gain (aOR 1.63; 95% CI 0.37–7.11); estimates were imprecise, however, and included the null (Table 2). Figure 1 shows the marginal odds ratios for stillbirth estimated from the model in which total weight gain was modelled as a continuous variable, and the estimated risks at each 0.5 SD weight gain z-score with increment compared to the risk at a weight gain z-score of 0. The high degree of overlap between crude and adjusted odds ratios suggests that there was minimal confounding. Figure 1A confirms that within the range of total weight gain for most normal-weight women (e.g. −2.0 SD to +2.0 SD) there was no clear association between weight gain z-score and stillbirth.

Table 3 and Figure 1D show results for normal-weight women and early pregnancy weight gain, and as with total weight gain, there was no association across the range of −2.0 SD to +2.0 SD. At the extremes of weight gain values (<−2.0 SD and ≥2.0 SD), the point estimates suggested protective effects of low weight gain (aOR 0.40; 95% CI 0.06–2.88) and increased risks of high weight gain (aOR 1.72; 95% CI 0.69–4.32), but confidence intervals were wide and included 1.

Overweight

As for normal-weight women, there were no observed associations between total and early weight gain z-score and stillbirth across the range of −2.0 SD to +2.0 SD (Tables 2 and 3) for overweight women.

In contrast with normal weight, the point estimates for overweight women at the extremes of the distributions suggested a higher risk at lower total-weight-gain values (aOR 1.97; 95% CI 0.69–5.62), and a lower risk at higher values (aOR 0.51; 95% CI 0.05–4.70). However, confidence intervals were wide and included the null (Table 2 and Figure 1B). The pattern for early-pregnancy weight gain showed similar results as those for the rest of the BMI categories: a tendency towards decreased risk at lower early weight gain (aOR 0.83; 95% CI 0.11–6.14) and increased

Table 2. Maternal total pregnancy weight gain by z-score categories with crude and adjusted odds ratios for stillbirth among 303 stillbirths and 1211 matched controls

BMI category	Weight gain		Control (*n*)	Stillbirth (*n*)	Crude odds ratio (95% CI)	Adjusted odds ratio* (95% CI)
	z-score category	Corresponding weight gain at 40 weeks (kg)				
Normal weight	<−2.0	<6.8	14	2	0.57 (0.13–2.51)	0.58 (0.13–2.63)
	−2.0 to −1.0	6.8 to 10.0	82	18	0.86 (0.50–1.49)	0.85 (0.48–1.49)
	−0.9 to 0.9	10.1 to 19.3	460	117	Ref	Ref
	1.0 to 1.9	19.4 to 25.8	92	23	0.98 (0.59–1.61)	1.03 (0.60–1.77)
	≥2.0	≥25.9	8	4	2.01 (0.58–7.00)	1.63 (0.37–7.11)
Over-weight	<−2.0	<4.5	15	6	1.67 (0.62–4.50)	1.97 (0.69–5.62)
	−2.0 to −1.0	4.5 to 8.5	33	8	1.02 (0.45–2.31)	0.82 (0.35–1.94)
	−0.9 to 0.9	8.6 to 20.3	274	67	Ref	Ref
	1.0 to 1.9	20.4 to 28.8	46	12	1.07 (0.54–2.16)	1.14 (0.55–2.36)
	≥2.0	≥28.9	7	1	0.56 (0.06–4.73)	0.51 (0.05–4.70)
Obese	<−2.0	<0.5	7	0	–	–
	−2.0 to −1.0	0.5 to 4.9	16	3	0.65 (0.18–2.32)	0.71 (0.17–2.93)
	−0.9 to 0.9	5.0 to 18.6	115	32	Ref	Ref
	1.0 to 1.9	18.7 to 29.0	31	9	1.07 (0.45–2.54)	1.12 (0.43–2.90)
	≥2.0	≥29.1	11	1	0.33 (0.04–2.72)	0.28 (0.03–2.59)

*Adjusted for maternal age, height, BMI, parity, smoking, living with partner, prepregnancy hypertension and diabetes.

risk at higher values (aOR 2.75; 95% CI 0.93–9.08; Table 3 and Figure 1E).

Obese

As for normal-weight and overweight women, there were no associations between total and early weight gain z-score and stillbirth across the range of −2.0 SD to +2.0 SD (Tables 2 and 3**,** Figures 1C and 1F) among the obese.

At the extreme values, a higher total weight gain (low weight gain could not be estimated) suggested a lower risk (aOR 0.28; 95% CI 0.03–2.59; Table 2), while the continuous estimates showed minimal association of low and high weight gain (Figure 1C). In contrast, results from the categorical model for early weight gain indicated an increased risk at both low (aOR 1.31; 95% CI 0.30–5.73) and high weight gain (aOR 2.20; 95% CI 0.29–16.64; Table 3), while the estimated marginal odds ratios from the continuous model showed a tendency towards a protective effect at low weight-gain values and increased risks at high values (Figure 1F). For both total and early pregnancy weight, however, the different analytical approaches consistently produced estimates compatible with a null effect and wide confidence intervals.

Adjustment for maternal age, height, BMI, parity, smoking, living with partner, prepregnancy hypertension and diabetes had little impact on the results in any of the analyses.

Comparison with IOM recommendations

Figure 1 also shows the risks of stillbirth in relation to the IOM pregnancy weight gain recommendations. At 40 weeks, the IOM recommendations corresponded to weight gain z-scores of −0.6 SD to +0.4 SD for normal-weight women, between −1.3 SD and −0.4 SD for overweight women, and −1.0 SD and −0.3 SD for obese women. There was no increased risk of stillbirth within the weight gain window of the current IOM recommendation (either for early or total weight gain z-scores), confirming that the range of weight gain values that optimises other maternal and child health outcomes is compatible with low stillbirth risk.

Discussion

Main findings

In this large population-based study, we found no associations between total or early pregnancy weight gain and stillbirth across the range of weight gain experienced by most women. At the extreme weight gain ranges, estimates were imprecise, and therefore an increased or decreased risk for extreme high/low weight gain cannot be ruled out. Further, within the current IOM recommendations for weight gain during pregnancy, there is no apparent association between weight gain during pregnancy and stillbirth. These findings support the validity of the IOM

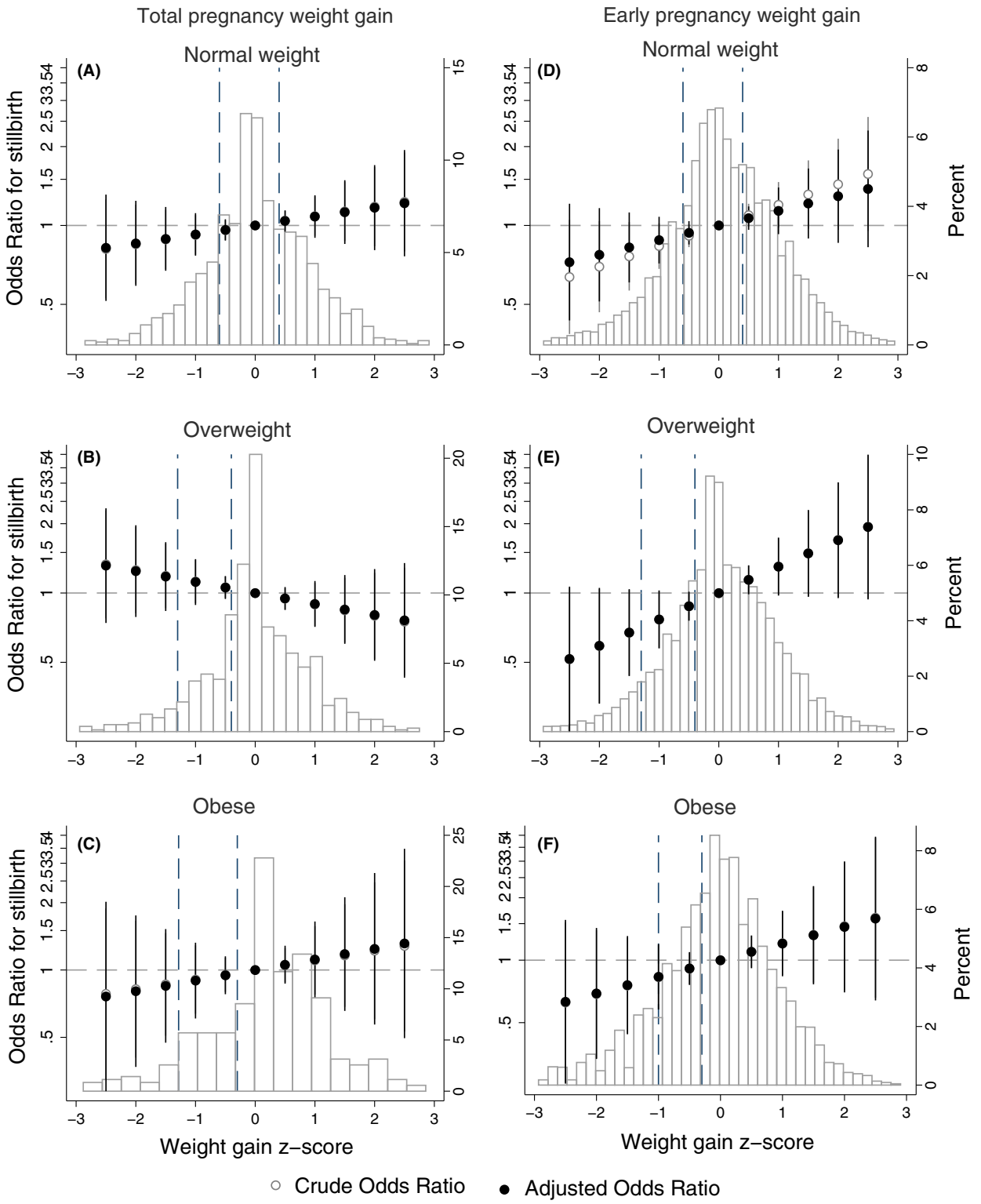

Figure 1. Maternal total and early pregnancy weight gain z-score and risk of stillbirth. This figure shows the association between maternal total (A–C) and early (D–F) pregnancy weight gain and risk of stillbirth. Estimates with 95% CI are marginal odds ratios for stillbirth at 0.5 increments of weight gain z-score in relation to a weight gain z-score of 0 (i.e., the 50th percentile) overlaid on the histogram of weight gain z-score with the distribution expressed as percentage. Dotted vertical lines denote the weight gain range of the current IOM recommendations. Adjustments were made for maternal age, height, BMI, parity, smoking, living with partner, prepregnancy hypertension and diabetes.

Table 3. Maternal weight gain by z-score categories for early pregnancy weight gain (until gestational week 22) with crude and adjusted odds ratios for stillbirth among 59 523 pregnancies

BMI category	Weight gain		Total (*n*)	Stillbirth (*n*)	Crude odds ratio (95% CI)	Adjusted odds ratio* (95% CI)
	z-score category	Corresponding weight gain at 22 weeks (kg)				
Normal weight	<−2.0	<1.1	971	1	0.40 (0.06–2.89)	0.40 (0.06–2.88)
	−2.0 to −1.0	1.1 to 2.8	3658	10	1.07 (0.55–2.06)	1.02 (0.51–2.04)
	−0.9 to 0.9	2.9 to 7.6	28 441	73	Ref	Ref
	1.0 to 1.9	7.7 to 10.9	5246	11	0.82 (0.43–1.54)	0.71 (0.37–1.38)
	≥2.0	≥11.0	1002	6	2.34 (1.02–5.39)	1.72 (0.69–4.32)
Over-weight	<−2.0	<−0.2	321	1	0.81 (0.11–5.93)	0.83 (0.11–6.14)
	−2.0 to −1.0	−0.2 to 1.9	1252	4	0.83 (0.30–2.34)	0.85 (0.3–2.40)
	−0.9 to 0.9	2.0 to 7.8	9910	38	Ref	Ref
	1.0 to 1.9	7.9 to 11.6	1627	7	1.12 (0.50–2.52)	1.14 (0.51–2.57)
	≥2.0	≥11.7	283	3	2.78 (0.85–9.07)	2.75 (0.83–9.08)
Obese	<−2.0	<−2.4	304	2	1.37 (0.32–5.81)	1.31 (0.30–5.73)
	−2.0 to −1.0	−2.4 to 0.0	688	2	0.60 (0.14–2.55)	0.62 (0.15–2.65)
	−0.9 to 0.9	0.1 to 6.5	4974	24	Ref	Ref
	1.0 to 1.9	6.6 to 10.8	746	4	1.11 (0.38–3.21)	1.06 (0.37–3.10)
	≥2.0	≥10.9	100	1	2.08 (0.28–15.55)	2.20 (0.29–16.64)

*Adjusted for maternal age, height, BMI, parity, smoking, living with partner, prepregnancy hypertension and diabetes.

recommended ranges, which were derived with only limited evidence of the link between weight gain and stillbirth.

Strengths and limitations

The large number of pregnancies enabled us to study rare outcomes such as stillbirth. In addition, the database contains detailed clinical data beyond the national Swedish Medical Birth Register, such as weight measurements during pregnancy and dates of last pregnancy weight measurements. This made it possible for us to study both early and total weight gain during pregnancy and to take the differences in gestational age of stillbirths and live births into account. Finally, our use of weight gain z-scores[12] instead of total weight gain in kilograms to account for the gestational-age-dependent nature of pregnancy weight gain allowed us to disentangle the effects of pregnancy weight gain on stillbirth from the effects of gestational duration.[9]

Despite our large sample size, the number of stillbirths was decreased when stratified by BMI-categories, especially among obese women. For this reason, we cannot rule out possible effects of extreme weight gain values on stillbirth risks. Moreover, we were unable to study the effect of weight gain during pregnancy on stillbirth in underweight women. Our analysis of total weight gain excluded 190 stillbirths without a gestational weight gain measurement within 31 days of delivery. The excluded stillbirths were more likely to be born to older mothers and at an earlier gestational age (leading to a lower total gestational weight gain in kilograms and fewer weight measurements) as compared with the included stillbirths. Our result of total weight gain and risk of stillbirth may therefore not take early stillbirths into account as much as those of later gestational age. Nevertheless, the gestational age of the included stillbirths ranged between 155 and 296 days (median: 261; interquartile range 213–280) and hence included stillbirths occurring at younger gestational ages. We also excluded women with missing early pregnancy BMI or weight gain data. The risk profile of these women differed from those included in the study (although weight patterns were similar), and as a result, we cannot rule out the potential for selection bias in our findings.

The sample consisted largely of white women, and uptake of publicly-funded antenatal care is nearly 100% in Sweden. For these reasons, the generalisability to other races or medical insurance systems is uncertain. The homogeneity of our study population is also a strength, however, as it helps to reduce the potential for confounding in our results by racial or socio-economic factors.

Interpretation

Little is known about the association between weight gain and stillbirth. The most recent IOM guidelines committee on pregnancy weight gain concluded that data on stillbirth and pregnancy weight gain was limited both in quality and quantity.[6] For this reason, stillbirth was not included as an

outcome when the weight gain recommendations were formulated. One study from the 1980s found that low weight gain among women with low prepregnancy BMI and excessive weight gain among women with high prepregnancy BMI were associated with an increased risk for stillbirth.[19] However, another study from the 1990s found no such association.[20] Similarly, a larger, more recent Swedish case-control study by Stephansson et al. included 649 stillbirth cases and 690 controls and found no association between gestational weight gain and antepartum stillbirths.[21] Our population-based cohort study extends the study of Stephansson et al.[21] by accounting for effect modification by early-pregnancy BMI and using a gestational age-independent measure of pregnancy weight gain.

There is growing recognition that there may be critical windows for the effect of weight gain on maternal and child outcomes. In particular, early pregnancy weight gain might be as or more important than late pregnancy weight gain (which previously had been believed to be the most important period) for long-term adiposity and cardiometabolic outcomes of the offspring.[10,11] The effect of early pregnancy weight gain on other maternal and child outcomes remains to be investigated, however. Like Stephansson et al.,[21] the current study, investigated the effect of early pregnancy weight gain and found no association between early pregnancy weight gain and stillbirth.

Studies of cause-specific stillbirth have found that prepregnancy obesity increased risks of stillbirth due to placental diseases, hypertension, fetal anomalies, and cord abnormalities (but not placental abruption or infection).[22] Future research to examine the effect of excess weight gain on cause-specific stillbirth may help to further elucidate potential mechanistic pathways.

Conclusion

Within the range of weight gain for most of our contemporary cohort of women with singleton births, there was no apparent association between early or total weight gain during pregnancy and stillbirth. However, estimates at the extremes of the weight gain ranges were imprecise because of sparse data. In particular, trends towards increased stillbirth risks with weight gain >+2.0 SD in normal-weight women warrant better understanding, which would require studies with even larger sample sizes. Collaborative efforts to combine estimates from different cohorts using individual patient meta-analysis or distributed regression approaches are therefore a worthwhile future research direction. There was no apparent association between weight gain and stillbirth within the weight gain window of the current IOM recommendation, confirming that the range of weight gain values that optimises other maternal and child health outcomes is compatible with low stillbirth risk.

Disclosure of interests

None declared. Completed disclosure of interests form available to view online as supporting information.

Contribution to authorship

JAH, KJ, and OS designed the research; JAH, KJ, LMB, SC, and OS conducted the research; JAH and KJ analysed data or performed statistical analysis; JAH and KJ drafted the manuscript; JAH, KJ, LMB, SC, and OS critically revised the manuscript for important intellectual content; JAH and KJ had primary responsibility for final content. All authors read and approved the final manuscript.

Details of ethics approval

This study was approved by the regional ethics committee at Karolinska Institutet, Stockholm, Sweden (DNR: 2013/792-32; approved April 30 2013).

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. Flow chart of included pregnancies among women delivering in the Stockholm and Gotland regions, Sweden, 2008-2014 for analysis of total and early pregnancy weight gain.

Table S1. Maternal and pregnancy characteristics among pregnancies included versus excluded (due to missing weight or missing early pregnancy BMI) in the Stockholm-Gotland region, Sweden 2008-2014.

Appendix S1. Conversion of z-scores to pregnancy weight gain in kilograms. ■

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