Original Contribution

Associations of Gestational Weight Gain With Short- and Longer-term Maternal and Child Health Outcomes

Emily Oken, Ken P. Kleinman, Mandy B. Belfort, James K. Hammitt, and Matthew W. Gillman

Initially submitted September 30, 2008; accepted for publication April 2, 2009.

The authors investigated the rate of gestational weight gain associated with the lowest combined risk of 5 short- and longer-term maternal and child health outcomes for 2,012 mother-child pairs recruited in 1999–2002 into Project Viva, a prebirth cohort study in Massachusetts. Within each maternal prepregnancy body mass index (BMI, kg/m²) stratum, they performed a logistic regression analysis predicting all 5 outcomes, from which they determined the rate of gain at which average predicted prevalence of the adverse outcomes was the lowest. The mean rate of total gestational weight gain was 0.39 kg/week (standard deviation, 0.14). The prevalence of small for gestational age was 6%, large for gestational age was 14%, preterm delivery was 7%, substantial postpartum weight retention was 16%, and child obesity was 10%. The lowest predicted outcome prevalence occurred with a 0.28-kg/week gain for women whose BMI was 18.5–24.9, a 0.03-kg/week loss for a BMI of 25.0–29.9, and a 0.19-kg/week loss for a BMI of ≥30.0 kg/m²—the lowest observed weight changes in overweight and obese women. For normal-weight and overweight women, lowest-risk gains varied modestly with adjustment for maternal characteristics and with different outcome weightings. For obese women, the lowest-risk weight change was weight loss in all models. Recommendations for gestational weight gain for obese women should be revised.

fetal development; obesity; pregnancy; premature birth; weight gain

Abbreviations: BMI, body mass index; LGA, large for gestational age; SGA, small for gestational age.

Maternal gestational weight gain is an important predictor of short- and longer-term outcomes of pregnancy (1), but the direction of effect differs by outcome. A large number of studies have found that higher maternal gestational weight gains are associated with decreased risk of small-for-gestational-age (SGA) birth, especially among underweight women, but with increased risk for large-for-gestational-age (LGA) birth and maternal postpartum weight retention (2). Very low and very high gestational weight gains increase risk of preterm delivery (2). Studies of gestational weight gain and child obesity are fewer; most (3–5), but not all (6), found that children born to mothers who gained more weight are also at elevated risk of becoming obese.

In 1990, the US Institute of Medicine published gestational weight gain recommendations that remain the standard today (7). Recommendations were for women with a normal body mass index (BMI) to gain 11.5–16.0 kg (0.29–0.40 kg/week), overweight women to gain 7.0–11.5 kg (0.18–0.29 kg/week), and obese women to gain at least 6 kg (0.15 kg/week). Some experts have since questioned whether weight gains within the ranges recommended by the Institute of Medicine are too high (8, 9). In addition, those recommendations provided little guidance about weight gain for obese women. Since a third of women of childbearing age are obese (10), minimizing adverse outcomes in this high-risk subgroup is a public health priority. The Institute of Medicine has recently convened a new committee to revise gestational weight gain recommendations. Determining optimal gestational weight gain is complicated by the fact that associations with outcomes may differ not only in strength and direction but also in seriousness. The few recent studies that have examined multiple outcomes at the time of birth have found that lowest-risk gains may be somewhat smaller than currently recommended.

Correspondence to Dr. Emily Oken, Department of Ambulatory Care and Prevention, Harvard Medical School and Harvard Pilgrim Health Care, 133 Brookline Avenue, Boston, MA 02215 (e-mail: emily_oken@hphc.org).
especially for obese women (11, 12). However, to our knowledge, no previous studies have simultaneously examined both short- and longer-term outcomes for mother and child, have quantitatively combined them, or have examined the effect of differentially weighting their importance.

In the present study, we used data from Project Viva, a longitudinal prebirth cohort study, to examine associations of gestational weight gain during pregnancy with risk of SGA, LGA, preterm delivery, substantial maternal postpartum weight retention, and child obesity. We identified the rate of total gestational weight gain associated with the lowest aggregate risk of the 5 outcomes for women entering pregnancy in different BMI categories. We also examined the extent to which lowest-risk gains varied with different outcome weightings.

MATERIALS AND METHODS

We recruited mothers into the Project Viva cohort between 1999 and 2002 when they presented for their initial prenatal clinical visit at one of 8 offices of a multispecialty group practice in eastern Massachusetts, as previously reported (13). Research assistants performed in-person visits with mothers at enrollment, at 26–28 weeks of gestation, and in the hospital following delivery and with mothers and children at 6 months and 3 years postpartum. At enrollment, we obtained information on maternal age, parity, smoking history, and race/ethnicity. All mothers provided informed consent. The human subjects committee of Harvard Pilgrim Health Care approved all study protocols, and all procedures were conducted in accordance with established ethical standards.

Of 2,128 mothers who delivered a live singleton, 2,092 (98%) had information on prepregnancy BMI, gestational weight gain, and at least one of the 5 outcomes of interest. We excluded 80 mothers whose prepregnancy BMI was below 18.5 kg/m². Of 2,012 mothers, 1,579 enrolled for study follow-up beyond 6 months postpartum. We had information on weight retention at 1 year postpartum for 1,198 mothers and on BMI for 1,205 children at age 3 years.

We recruited mothers into the Project Viva cohort between 1999 and 2002 when they presented for their initial prenatal clinical visit at one of 8 offices of a multispecialty group practice in eastern Massachusetts, as previously reported (13). Research assistants performed in-person visits with mothers at enrollment, at 26–28 weeks of gestation, and in the hospital following delivery and with mothers and children at 6 months and 3 years postpartum. At enrollment, we obtained information on maternal age, parity, smoking history, and race/ethnicity. All mothers provided informed consent. The human subjects committee of Harvard Pilgrim Health Care approved all study protocols, and all procedures were conducted in accordance with established ethical standards.

We excluded 80 mothers whose prepregnancy BMI was below 18.5 kg/m². Of 2,012 mothers, 1,579 enrolled for study follow-up beyond 6 months postpartum. We had information on weight retention at 1 year postpartum for 1,198 mothers and on BMI for 1,205 children at age 3 years. Compared with the 807 mothers whose children were not measured at age 3 years, the 1,205 mothers whose children were measured at age 3 years had a somewhat lower mean prepregnancy BMI (24.8 kg/m² vs. 25.7 kg/m²) but no difference in total gestational weight gain (0.39 kg/week vs. 0.39 kg/week).

Maternal BMI and gestational weight gain

At enrollment, we obtained maternal self-reported prepregnancy weight and height, from which we calculated prepregnancy BMI. We determined total gestational weight gain as the difference between self-reported prepregnancy weight and the last clinically measured weight recorded prior to delivery. We performed a validation study comparing self-reported prepregnancy weight with clinically measured weight recorded in the medical record within 3 months prior to the last menstrual period. Correlation coefficients ($r = 0.99$ overall) and mean underreporting of weight (approximately 1 kg) did not differ by race/ethnicity, gestational age at study enrollment, or weight itself (4). We calculated the rate of total gestational gain by dividing the total kilograms gained by the number of weeks between the last menstrual period and the last recorded weight before delivery.

Outcomes

We calculated gestation length from the last menstrual period. Among women for whom the prenatal ultrasound estimate differed from the last menstrual period estimate by more than 10 days, we calculated gestation length using the ultrasound results. The proportion for whom we used the ultrasound estimate was the same regardless of maternal prepregnancy BMI (12%). We defined preterm births as less than 37 completed weeks of gestation and compared them with births at 37 or more weeks. We obtained infant birth weight and route of delivery from hospital medical records. We calculated percentiles of birth weight for gestational age using US national reference data (14). We defined SGA as birth weight for gestational age and sex below the 10th percentile and compared these births with non-SGA births. We defined LGA as birth weight for gestational age and sex above the 90th percentile and compared these births with non-LGA births.

We calculated postpartum weight retention as the difference in weight reported by mothers at 12 months following delivery and prepregnancy weight reported at study enrollment. We defined substantial postpartum weight retention as weight retention of at least 5 kg compared with weight retention of less than 5 kg.

When children reached age 3 years, we performed in-person study visits in a research office or in participants’ homes. We measured heights and weights using a calibrated stadiometer (Shorr Productions, Olney, Maryland) and scale (Seca model 881; Seca Corp., Hanover, Maryland). We calculated age- and sex-specific BMI percentiles using 2000 Centers for Disease Control and Prevention reference data (15). We defined obesity as BMI above the 95th percentile compared with below the 85th percentile.

Statistical analysis

We stratified all analyses by prepregnancy BMI. For our primary analyses, we defined normal weight as a BMI of 18.5–24.9 kg/m², overweight as a BMI of 25.0–29.9 kg/m², and obesity as a BMI of 30.0 kg/m² or greater. In secondary analyses, we created BMI categories as used by the Institute of Medicine (7) (normal, 19.8–25.9 kg/m²; high, 26.0–29.0 kg/m²; and obese, >29.0 kg/m²). In additional analyses, we recalculated prepregnancy BMI and gestational weight gain assuming that all mothers had underreported their prepregnancy weight by 1 kg or by 10%.

Within each BMI stratum, we performed a logistic regression analysis predicting all 5 outcomes. The model is effectively the same as 5 logistic regressions, each fitting a different outcome, but is corrected for correlation among outcomes within each individual. We used generalized estimating equations (16, 17) with an unstructured correlation matrix and report robust standard errors here.

The primary predictor was rate of total gestational weight gain. In all models, we also included maternal prepregnancy BMI as a continuous measure. Inclusion of an additional quadratic term for rate of gain did not improve model fit, so, in this paper, we report results from models without this term. We also modeled gestational weight gain in categories each with about 10 individuals and in 4 categories according to Nohr et al. (18). In additional models, we adjusted for maternal race/ethnicity, age, smoking status, and parity. We used estimates from these models to generate predicted probabilities of each of the 5 outcomes within each maternal BMI stratum. To generate these predicted probabilities, we fixed maternal prepregnancy BMI at the mean BMI observed within the stratum and allowed gestational weight gain to vary across the observed range within that stratum. We then calculated the average probability of the 5 outcomes. We identified the lowest-risk gain for each BMI category as the rate of gestational weight gain at which the average predicted probability of the 5 adverse outcomes was the lowest. To generate predicted outcome probabilities in the adjusted models, we assigned race/ethnicity as white, age as 32 years, parity as 0, and smoking as never.

We performed all analyses using SAS version 9.1 software (SAS Institute, Inc., Cary, North Carolina).

RESULTS

Of 2,012 mothers, 61% were of normal weight entering pregnancy (BMI 18.5–24.9 kg/m²), 23% were overweight (BMI 25.0–29.9 kg/m²), and 16% were obese (BMI ≥30 kg/m²) (Table 1). Within each BMI category, the rate of gestational weight gain was approximately normally distributed among the children in each category. To determine how lowest-risk gains varied when certain outcomes had more influence than the others, we calculated a weighted average of the probability of the outcomes by multiplying the predicted probabilities of selected outcomes by integer weights and dividing the sum of these products by the sum of the weights. We chose these weights by a convenience survey of 12 pediatric researchers at Harvard Medical School, in which we asked them to rank the 5 outcomes in order of most to least adverse and then to indicate how many times worse the most adverse outcome was than the least adverse outcome.

Table 1. Prevalence of 5 Maternal and Child Health Outcomes According to Characteristics of 2,012 Massachusetts Mothers Enrolled in Project Viva, 1999–2002

<table>
<thead>
<tr>
<th>Maternal Characteristic</th>
<th>Prevalence of Characteristic No.</th>
<th>%</th>
<th>Mean (SD) Prepregnancy BMI, kg/m²</th>
<th>Preterm Delivery (&lt;37 Weeks; 145/2,012a)</th>
<th>Small for Gestational Age (&lt;10th Percentile; 124/2,011)</th>
<th>Large for Gestational Age (&gt;90th Percentile; 278/2,011)</th>
<th>Substantial Maternal Postpartum Weight Retention (≥5 kg at 1 Year; 192/1,198)</th>
<th>Child Obesity at Age 3 Years (BMI &gt;95th Percentile; 116/1,205)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>2,012</td>
<td>100</td>
<td>25.2 (5.4)</td>
<td>7</td>
<td>6</td>
<td>14</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>Age, years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;20</td>
<td>61</td>
<td>3</td>
<td>24.6 (5.0)</td>
<td>10</td>
<td>18</td>
<td>5</td>
<td>41</td>
<td>6</td>
</tr>
<tr>
<td>20–34</td>
<td>1,398</td>
<td>70</td>
<td>25.2 (5.5)</td>
<td>8</td>
<td>6</td>
<td>13</td>
<td>17</td>
<td>9</td>
</tr>
<tr>
<td>≥35</td>
<td>552</td>
<td>27</td>
<td>25.1 (5.2)</td>
<td>6</td>
<td>5</td>
<td>18</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>Race/ethnicity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>330</td>
<td>16</td>
<td>27.8 (6.5)</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td>30</td>
<td>13</td>
</tr>
<tr>
<td>Hispanic</td>
<td>149</td>
<td>7</td>
<td>25.8 (5.2)</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>26</td>
<td>16</td>
</tr>
<tr>
<td>Other</td>
<td>193</td>
<td>10</td>
<td>24.8 (5.5)</td>
<td>13</td>
<td>13</td>
<td>10</td>
<td>26</td>
<td>5</td>
</tr>
<tr>
<td>White</td>
<td>1,339</td>
<td>67</td>
<td>24.5 (4.9)</td>
<td>6</td>
<td>4</td>
<td>16</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Prepregnancy BMI, kg/m²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18.5–24.9</td>
<td>1,227</td>
<td>61</td>
<td>21.8 (1.7)</td>
<td>7</td>
<td>7</td>
<td>11</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>25.0–29.9</td>
<td>456</td>
<td>23</td>
<td>27.1 (1.4)</td>
<td>7</td>
<td>5</td>
<td>18</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>≥30.0</td>
<td>328</td>
<td>16</td>
<td>35.1 (4.6)</td>
<td>9</td>
<td>5</td>
<td>18</td>
<td>26</td>
<td>23</td>
</tr>
<tr>
<td>Smoking history</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During pregnancy</td>
<td>220</td>
<td>11</td>
<td>26.2 (5.9)</td>
<td>9</td>
<td>11</td>
<td>12</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>Missing/former</td>
<td>508</td>
<td>25</td>
<td>25.2 (5.2)</td>
<td>6</td>
<td>5</td>
<td>17</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>Never</td>
<td>1,283</td>
<td>64</td>
<td>25.0 (5.4)</td>
<td>8</td>
<td>6</td>
<td>13</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>Parity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>961</td>
<td>48</td>
<td>24.5 (4.9)</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>19</td>
<td>7</td>
</tr>
<tr>
<td>≥1</td>
<td>1,050</td>
<td>52</td>
<td>25.8 (5.8)</td>
<td>6</td>
<td>4</td>
<td>18</td>
<td>13</td>
<td>12</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index; SD, standard deviation.

a Values are expressed as number of children affected/total number of children assessed.

The primary predictor was rate of total gestational weight gain. In all models, we also included maternal prepregnancy BMI as a continuous measure. Inclusion of an additional quadratic term for rate of gain did not improve model fit, so, in this paper, we report results from models without this term. We also modeled gestational weight gain in categories each with about 10 individuals and in 4 categories according to Nohr et al. (18). In additional models, we adjusted for maternal race/ethnicity, age, smoking status, and parity. We used estimates from these models to generate predicted probabilities of each of the 5 outcomes within each maternal BMI stratum. To generate these predicted probabilities, we fixed maternal prepregnancy BMI at the mean BMI observed within the stratum and allowed gestational weight gain to vary across the observed range within that stratum. We then calculated the average probability of the 5 outcomes. We identified the lowest-risk gain for each BMI category as the rate of gestational weight gain at which the average predicted probability of the 5 adverse outcomes was the lowest. To generate predicted outcome probabilities in the adjusted models, we assigned race/ethnicity as white, age as 32 years, parity as 0, and smoking as never.

distributed. The mean rate of total gestational weight gain was 0.39 kg/week (standard deviation, 0.14; range, −0.19 to 1.03) overall, 0.41 kg/week (standard deviation, 0.12; range, −0.05 to 1.03) for normal-weight women, 0.40 kg/week (standard deviation, 0.15; range, −0.03 to 0.88) for overweight women, and 0.31 kg/week (standard deviation, 0.19, range, −0.19 to 0.93) for obese women. Only one woman in each of the normal-weight and overweight BMI groups lost weight during pregnancy, but 12 (1.2%) obese women lost weight. The rate of total gestational weight gain to delivery was 0.35 kg/week among those who delivered preterm. The rate of gestational weight gain to week 32 of gestation was 0.35 kg/week among those who delivered preterm and 0.38 kg/week among those who delivered at term.

The prevalence of SGA was 6% and the prevalence of LGA was 14%; thus, babies in this cohort were somewhat heavier compared with US population norms of 10% for both outcomes. The prevalence of preterm delivery was 7%, of substantial postpartum weight retention was 16%, and of child obesity was 10%. In Table 1, we present the prevalence of these 5 outcomes according to selected maternal characteristics. Gestational weight gain was not associated with risk of cesarean section (data not shown).

Among all women, gestational weight gain was directly associated with risk of substantial postpartum weight retention and child obesity, although estimates for child obesity were less strong and confidence intervals crossed 1.0 among normal-weight and obese women (Table 2). Gestational weight gain was also directly associated with risk of LGA among normal-weight and overweight women, whereas it was inversely associated with risk of SGA and preterm delivery among normal-weight women. Among overweight women, associations of higher gestational weight gain with lower risk of SGA and preterm birth were not statistically significant. Among obese women, gestational weight gain was not associated with risk of LGA, SGA, or preterm birth.

In Figure 1, we display the predicted prevalence of each of the 5 adverse outcomes according to the total gestational rate of gain, stratified by maternal prepregnancy BMI. The left and right limits of the lines in each panel represent the lowest and highest observed values, respectively, of rate of gestational gain within that BMI stratum.

The lowest predicted prevalence of all 5 adverse outcomes occurred with a gestational gain of 0.28 kg/week for normal-weight women, a loss of 0.03 kg/week for overweight women, and a loss of 0.19 kg/week for obese women (Table 3 and Figure 2). For overweight and obese women, these values represent the lowest weight change observed. Over 40 weeks of gestation, these rates would correspond to a gain of 11.2 kg for normal-weight women, a loss of 1.2 kg for overweight women, and a loss of 7.6 kg for obese women.

Estimates for normal-weight women varied somewhat according to the value of maternal BMI we used for predicted models. If, instead of the mean BMI (22.1 kg/m²), we used the lowest observed value (18.5 kg/m²), the lowest predicted outcome prevalence occurred at a gain of 0.36 kg/week, whereas if we used a BMI of 24.9 kg/m², the lowest predicted outcome prevalence occurred at a gain of 0.21 kg/week. Estimates for overweight and obese women did not change according to the value of maternal BMI used in prediction models.

Estimates for the gain associated with the lowest risk were similar when we assumed that all women underreported their prepregnancy weight by 1 kg (0.27 for normal-weight, −0.07 for overweight, and −0.21 kg/week for obese women) or by 10% (0.31 for normal-weight, −0.03 for overweight, and −0.17 kg/week for obese women) or when we categorized maternal BMI according to the cutpoints used in the 1990 Institute of Medicine report (0.27 for normal-weight, 0.08 for overweight, and −0.19 kg/week for obese women). Results were also similar when we restricted our analysis to the 985 mother-child pairs with information on all 5 outcomes or when we modeled gestational weight gain in categories rather than as a continuous exposure (data not shown). When we included maternal race/ethnicity, age, parity, and smoking in multivariate models, estimates varied minimally for normal-weight and overweight women and did not change for obese women (Table 3).

For the above analyses, we assumed that each of the 5 outcomes was equally undesirable. We next explored the effect of weighting the outcomes. In our convenience survey, 5 local experts ranked preterm birth as the worst outcome, with an average weight of 6. Three ranked child obesity as the worst outcome, with an average weight of

<table>
<thead>
<tr>
<th>Maternal Prepregnancy BMI, kg/m²</th>
<th>Preterm Delivery (&lt;37 weeks)</th>
<th>Small for Gestational Age (&lt;10th Percentile)</th>
<th>Large for Gestational Age (&gt;90th Percentile)</th>
<th>Substantial Maternal Postpartum Weight Retention (≥5 kg at 1 Year)</th>
<th>Child Obesity at Age 3 Years (BMI &gt;95th Percentile)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR 95% CI</td>
<td>OR 95% CI</td>
<td>OR 95% CI</td>
<td>OR 95% CI</td>
<td>OR 95% CI</td>
</tr>
<tr>
<td>18.5–24.9</td>
<td>0.72 (0.56, 0.92)</td>
<td>0.68 (0.54, 0.85)</td>
<td>1.43 (1.24, 1.64)</td>
<td>1.68 (1.40, 2.01)</td>
<td>1.16 (0.88, 1.51)</td>
</tr>
<tr>
<td>25.0–29.9</td>
<td>0.85 (0.65, 1.10)</td>
<td>0.87 (0.63, 1.19)</td>
<td>1.29 (1.09, 1.52)</td>
<td>1.97 (1.55, 2.50)</td>
<td>1.35 (1.01, 1.81)</td>
</tr>
<tr>
<td>≥30.0</td>
<td>0.97 (0.81, 1.16)</td>
<td>1.01 (0.81, 1.25)</td>
<td>1.08 (0.92, 1.27)</td>
<td>1.79 (1.37, 2.34)</td>
<td>1.22 (0.96, 1.56)</td>
</tr>
</tbody>
</table>

Abbreviation: BMI, body mass index.

* Results from a logistic regression analysis predicting all 5 outcomes. Shown are the odds ratio (OR) and 95% confidence interval (CI) for each outcome per 0.1-kg/week of gestational weight gain.
2; 3 ranked substantial postpartum weight retention as the worst, with an average weight of 3; and 1 ranked SGA as the worst, with a weight of 6. None ranked LGA as the worst outcome. Weighting preterm birth 6-fold worse or SGA 5-fold worse than the other outcomes shifted estimates of lowest-risk gestational weight gain higher, whereas weighting child obesity 2-fold worse or maternal substantial postpartum weight retention 3-fold worse than the others shifted estimates somewhat lower (Table 3). Estimates of lowest-risk gain for obese women did not shift from the lowest observed value in any of the models (Table 3). When all of these weights were included simultaneously, lowest-risk gains were above the range currently recommended by the Institute of Medicine for normal-weight women (0.42 kg/week) but remained below current recommendations for overweight and obese women. In all models, the lowest-risk weight change among obese women was the lowest observed value, that is, weight loss during pregnancy.

DISCUSSION

In this analysis considering 5 short- and longer-term outcomes, we found that lowest-risk gestational weight gains were within currently recommended ranges for women who were normal weight entering pregnancy but were lower than current recommendations for overweight and obese women. When we allowed different outcome weights, estimates of lowest-risk gain varied modestly for normal-weight and overweight women. In contrast to the current recommendation that obese women should gain at least 6 kg, in all models, the lowest predicted prevalence of adverse outcomes for obese women occurred with weight loss.

A number of studies have examined associations of gestational weight gain with individual pregnancy outcomes, such as fetal growth or gestation length. Fewer have examined multiple outcomes of pregnancy, labor, and delivery, and they have done so mostly according to gestational weight gain in broad categories, which does not allow for refined estimation of optimal gain (19–22).

In a study of birth certificate data from obese women in Missouri, Kiel et al. (11) found that lowest-risk gestational weight change ranged from a gain of 4.5–11.4 kg for women with a BMI of 30–35 kg/m² to a loss of 1 kg or more for women with a BMI of 40 kg/m² or greater. In a companion study, lowest-risk gain among Missouri women with a normal prepregnancy BMI was within current Institute of Medicine guidelines, mainly because of increasing SGA risk with higher gains (23). However, the authors of these studies apparently determined optimal gain by visually inspecting the separate outcomes rather than by combining outcomes or using a mathematical approach, as we did. Cedergren (12) studied multiple pregnancy complications among women in Sweden. In that analysis, adverse outcomes were minimized at gains of 4–10 kg among women with a BMI of less than 20 kg/m², 5–22 kg among women with a BMI of 20–24.9 kg/m², less than 9 kg for women with a BMI of 25–29.9 kg/m², and less than 6 kg for women with a BMI of 30 kg/m² or greater. Notably, for overweight and obese
which enabled us to determine lowest-risk weight change observed gain for each BMI category, including weight loss, gain as a continuous measure across the entire range of different outcome weightings.

Outcomes was minimized, and did not examine the influence of smoking. Additionally, they did not allow refined estimates of optimal gain or allow for the possibility of studying weight loss. These authors studied total gestational weight gain in women, risks appeared to continue to decline below the lowest recorded value (0 kg of gain). However, the author did not provide any detail regarding the way in which the outcomes were combined. In contrast to lower optimal gains implied by those studies, among a population of women who delivered at a single hospital in New York City from 1987 to 1993, gains associated with optimal birth outcomes were somewhat higher than Institute of Medicine guidelines (24).

Nohr et al. (18) studied associations of gestational weight gain with outcomes at birth, including SGA and LGA, preterm delivery, maternal postpartum weight retention at 1 year, and child obesity at age 3 years.

Table 3. Rates of Total Gestational Weight Gain (kg/week) Associated With the Lowest Predicted Prevalence of 5 Adverse Outcomes, in Models Unadjusted, Adjusted, and With Different Outcome Weights Applied, Among 2,012 Massachusetts Mother-Child Pairs Enrolled in Project Viva, 1999–2002

<table>
<thead>
<tr>
<th>Maternal Prepregnancy BMI, kg/m²</th>
<th>18.5–24.9</th>
<th>25.0–29.9</th>
<th>≥30.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unweighted estimates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unadjusted</td>
<td>0.28</td>
<td>−0.03a</td>
<td>−0.19b</td>
</tr>
<tr>
<td>Adjusted for maternal race/ethnicity, age, parity, and smokingc</td>
<td>0.31</td>
<td>0.01</td>
<td>−0.19b</td>
</tr>
<tr>
<td>Estimates with weightings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preterm × 6</td>
<td>0.47</td>
<td>0.24</td>
<td>−0.19b</td>
</tr>
<tr>
<td>SGA × 5</td>
<td>0.46</td>
<td>0.13</td>
<td>−0.19b</td>
</tr>
<tr>
<td>Child obesity × 2</td>
<td>0.26</td>
<td>−0.03‡</td>
<td>−0.19b</td>
</tr>
<tr>
<td>Substantial postpartum weight retention × 3</td>
<td>0.18</td>
<td>−0.03</td>
<td>−0.19b</td>
</tr>
<tr>
<td>Preterm × 6, SGA × 5, child obesity × 2, substantial postpartum weight retention × 3, and LGA × 1</td>
<td>0.42</td>
<td>0.16</td>
<td>−0.19b</td>
</tr>
<tr>
<td>Preterm × 6, SGA × 5, child obesity × 2, substantial postpartum weight retention × 3, and LGA × 1; also adjusted for maternal race/ethnicity, age, parity, and smokingc</td>
<td>0.42</td>
<td>0.15</td>
<td>−0.19b</td>
</tr>
</tbody>
</table>

Abbreviation: BMI, body mass index.

a Small for gestational age (SGA), large for gestational age (LGA), preterm delivery, maternal postpartum weight retention at 1 year, and child obesity at age 3 years.

b Lowest observed rate of gain in the study population.

c Covariates were modeled as follows: race/ethnicity (white, black, other), age (continuous years), parity (nulliparous, parous), smoking (never, during pregnancy, former). To generate predicted probabilities, we assigned race/ethnicity = white, age = 32 years, parity = 0, and smoking = never.

Women, risks appeared to continue to decline below the lowest recorded value (0 kg of gain). However, the author did not provide any detail regarding the way in which the outcomes were combined. In contrast to lower optimal gains implied by those studies, among a population of women who delivered at a single hospital in New York City from 1987 to 1993, gains associated with optimal birth outcomes were somewhat higher than Institute of Medicine guidelines (24).

Nohr et al. (18) studied associations of gestational weight gain with outcomes at birth, including SGA and LGA, preterm delivery, maternal postpartum weight retention at 6 months postpartum among mother-child pairs in the Danish National Birth Cohort. They concluded that heavier women may benefit from avoiding “high” and “very high” gains. These authors studied total gestational weight gain in 4 categories (<10 kg, 10–15 kg, 16–19 kg, ≥20 kg), which did not allow refined estimates of optimal gain or allow for the possibility of studying weight loss. Additionally, they examined each outcome individually, did not attempt to determine the range of weight gain at which the sum of all outcomes was minimized, and did not examine the influence of different outcome weightings.

In the present analysis, we examined gestational weight gain as a continuous measure across the entire range of observed gain for each BMI category, including weight loss, which enabled us to determine lowest-risk weight change without predefined categories. We considered multiple short- and longer-term outcomes simultaneously, including child obesity, and thus were able to account for interrelations between outcomes, to sum the predicted prevalence of the several outcomes, and to examine the influence of different outcome weightings on results.

We recognize that the outcome weightings we applied may not accurately reflect the relative severity of the studied outcomes. For example, in populations in which cesarean delivery is not readily available, LGA births may result in more serious complications and thus might be weighted more strongly. In a review of the literature, we were unable to find standard values, such as utilities, for the outcomes of interest. Identifying the “right” weights for each outcome would require separate, comprehensive studies for each one. However, once identified, those weights could be applied to an analysis such as ours. The variations in predicted lowest-risk gain were modest across the weightings we used, but the results suggested that higher gains might be preferable for normal-weight and overweight women if SGA or preterm birth is substantially worse than the other outcomes, whereas lower gains improved combined outcomes if maternal postpartum weight retention or child obesity is rated worse.

Small numbers limited our ability to perform detailed analyses of women with a BMI of less than 18.5 kg/m². We were unable to include rare outcomes such as stillbirth.
or infant death, or complications of delivery, although associations of gestational gain with these outcomes may be largely mediated by influences on fetal growth or preterm birth. We did not evaluate associations with pregnancy complications such as gestational diabetes mellitus or pre-eclampsia, because these conditions occur before pregnancy is completed and may influence later gain. As is the case in most studies of gestational weight gain, we relied on self-reported prepregnancy weight. However, in our validation study, we saw no evidence that reporting was biased according to maternal weight, and accounting for possible underreporting by 1 kg did not markedly influence our estimates. Misclassification of gestational age would influence our calculation of the rate of gestational gain and could thereby influence results, although we saw no evidence that gestational age determination differed by prepregnancy BMI. Because this study was observational, we could not determine whether associations were causal.

Since women in the cohort all had health insurance, were generally well educated, and resided in and around Massachusetts, results may not be generalizable to populations elsewhere. Other studies included larger, more representative populations. The present results may not apply to all women. Advantages of studying this cohort over using a larger, administrative database include a well-characterized study population and research-quality assessment of outcome measures.

The Institute of Medicine’s new guidelines for gestational weight gain should consider the risks and benefits of various amounts of gain for both mothers and children, and for both short- and longer-term outcomes. In this study, we estimated weight gains associated with the lowest risk of 5 short- and long-term outcomes simultaneously. Our results suggest that weight gain recommendations for overweight and obese women should be lowered to minimize adverse health outcomes for mothers and their children.

ACKNOWLEDGMENTS

Author affiliations: Obesity Prevention Program, Department of Ambulatory Care and Prevention, Harvard Medical School and Harvard Pilgrim Health Care, Boston, Massachusetts (Emily Oken, Ken P. Kleinman, Matthew W. Gillman); Department of Newborn Medicine, Children’s Hospital Boston, Boston, Massachusetts (Mandy B. Belfort); Center for Risk Analysis, Harvard School of Public Health, Boston, Massachusetts (James K. Hammitt); and Department of Nutrition, Harvard School of Public Health, Boston, Massachusetts (Matthew W. Gillman).

This study was funded by grants from the US National Institutes of Health (HD 34568, HL 64925, HL 68041, HD 44807) and by Harvard Medical School and the Harvard Pilgrim Health Care Foundation.

Conflict of interest: none declared.
REFERENCES


