Optimal gestational weight gain ranges for the avoidance of adverse birth weight outcomes: a novel approach

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ABSTRACT

Background: Gestational weight gain (GWG) has been shown to be directly associated with birth weight.

Objective: We aimed to define ranges for optimal GWG with respect to the risk of either small- or large-for-gestational-age offspring by using a new statistical approach.

Design: For the purpose of an observational study, data on n = 177,079 mature singleton deliveries in Bavaria between 2004 and 2006 were extracted from a standard data set that is regularly collected for national benchmarking of obstetric units in terms of clinical performance. Joint predicted risks of either small- or large-for-gestational-age births in relation to GWG (continuous measurement) were estimated by logistic regression models with adjustment for potential confounders.

Results: The estimated optimal GWG ranges as defined by a joint predicted risk of ≤20% were substantially wider than those recommended by the Institute of Medicine for underweight (8–25 compared with 12.5–18.0 kg) and normal-weight (2–18 compared with 11.5–16.0 kg) women. Overweight and obese women’s optimal GWG ranged from −7 to 12 and −15 to 2 kg, respectively (Institute of Medicine recommendations: 7.0–11.5 and 5.0–9.0 kg, respectively). We observed considerable effect modifications by parity and smoking in pregnancy. In normal-weight primiparae, for example, the optimal GWG range was 10–26 kg for nonsmokers compared with 23–27 kg for smokers.

Conclusions: Considerably wider optimal GWG ranges than recommended by the Institute of Medicine might be tolerated with respect to avoidance of adverse birth weight outcome. Stratification by maternal body mass index category alone might not be sufficient.


INTRODUCTION

Optimal birth is of major importance for perinatal morbidity and mortality (1, 2) as well as for health later in life. Whereas long-term effects of low birth weight are associated with central obesity (3), hypertension (4), hyperlipidemia (5), and impaired cognitive capacity (6), high birth weight is related to an increased risk of obesity later in life (3).

Numerous factors are associated with birth weight, such as parity and child’s sex (7), maternal and gestational diabetes (8, 9), maternal smoking during pregnancy (10), maternal overweight (11), and gestational weight gain (GWG) (12–14). Several of these factors are difficult or impossible to influence. GWG has recently gained particular interest in this context, because it may be modified by diet (15) and physical activity (16–18). Increases in GWG over time have been shown in several populations (19, 20).

A recent study by Nohr et al (21) showed that low GWG increases the risk of low birth weight and decreases the risk of high birth weight, whereas high GWG causes the opposite effects. The ranges of “optimal” GWG varied with maternal prepregnancy body mass index (BMI; in kg/m²) and differed considerably from the Institute of Medicine (IOM) recommendations of 1990 (22).

A weakness of this study is that GWG was assessed in only 4 discrete categories, which accounted for discontinuities in the definition of optimal ranges. More-accurate estimates may be obtained with GWG as a continuous variable. Additionally, other risk factors for low and high birth weight, such as smoking and parity, were considered only as confounders and not as effect modifiers.

We therefore adopted an alternative approach and considered these factors as well as BMI in terms of interactions in the association between GWG and extreme birth weight. Joint predicted risks of small-for-gestational-age (SGA) or large-for-gestational-age (LGA) children were based on GWG as a continuous variable.

SUBJECTS AND METHODS

Data

Maternal and neonatal data on n = 275,708 mature (37 completed weeks of gestation or later) singleton deliveries in Bavarian obstetric units from 2004 to 2006 were available. These included anthropometric measurements of the women in...
early pregnancy and before delivery and of the newborns. Gestational age was calculated from expected date of delivery on the basis of the date of last menstrual period and corrected by crown-rump-length as measured by first trimester ultrasound, if both estimates differed considerably.

The data used for analysis were extracted from a standard data set regularly collected electronically for the national benchmarking of obstetric units in terms of clinical performance. The Bayerische Arbeitsgemeinschaft für Qualitätssicherung (BAQ), the Bavarian working group on clinical quality assessment, conducts corresponding regional evaluations for the “Bundesland of Bavaria.” Data are transferred electronically to the BAQ office after personal, identifying characteristics have been removed and replaced by an anonymous, unique reference number.

Information on maternal weight and gestational age at booking, as well as information on smoking habit, were abstracted by midwives and nurses from the mothers’ pregnancy booklets and augmented by additional information on admission to hospital. Neonatal anthropometric data were abstracted from the hospital records. GWG was calculated only for bookings before the 14th week of gestation as last weight before delivery minus maternal weight at booking. In accordance with Nohr et al (21), we excluded mothers with preeclampsia, gestational diabetes, or diabetes mellitus or those aged <18 y (n = 11,385). Further exclusions pertained to mothers with missing, extreme, or implausible values of maternal height (<100 or >220 cm), weight at first antenatal care visit or before delivery (<30 or >300 kg), or GWG (< −30 or >50 kg) and children with reported birth weights <1000 g, which amounted to 32,244 exclusions. A further 17,288 mothers were excluded because their date of booking was after the 13th week of gestation or was unknown. Information on smoking during pregnancy was missing for a further 37,709 mothers, and on other covariates in 3 cases, which ultimately left n = 177,079 cases for a complete case analysis.

Statistical analyses

Initially, we performed a linear regression with birth weight as the dependent variable and GWG as the explanatory variable, with adjustment for child’s sex, parity, gestational age, maternal age, maternal BMI, smoking during pregnancy, foreign country of origin, and single parent status. In the next step, we included bivariate interaction terms between GWG and all covariates from above to identify possible effect modifiers. Because of the large sample size, an effect was considered significant if the respective P value was <0.01.

Logistic regression models were calculated separately to assess the risk of SGA or LGA with respect to GWG in kilograms as a continuous variable. SGA and LGA were defined in terms of birth weight below or above the respective national 10th or 90th birth weight percentile (23). These percentiles are sex and gestational age specific, which thus obviated the need for further adjustment for these variables. All logistic models were stratified by maternal BMI and adjusted for the potential confounders country of origin (German/non-German), single-parent status, smoking, parity (primiparous compared with multiparous), and maternal age. Maternal weight status in early pregnancy was classified in terms of BMI at booking into 4 categories, in accordance with the standards of the World Health Organization (24):

1) Underweight: BMI < 18.5
2) Normal weight: 18.5 ≤ BMI < 25
3) Overweight: 25 ≤ BMI < 30
4) Obese: BMI ≥ 30

Prediction models for SGA and LGA were estimated with the estimated logistic regression coefficients and all confounders fixed at their modes and means (as appropriate). We explored GWG values in the range of −30 to 50 kg in these prediction models to obtain the predicted risks of SGA and LGA as a sole function of GWG.

The risk of an adverse birth weight outcome was assessed as the sum of the predicted risks of SGA and LGA for each inspected GWG value. A joint predicted risk (JPR) of ≥20% for the occurrence of either SGA or LGA would be expected a priori, because these 2 outcomes were defined by the lower and upper 10%, respectively, of observed birth weights in the reference population (23). Therefore, “optimal” GWG range was identified by a maximum of 20% JPR.

The results were compared with the IOM’s new criteria for insuffi ci ent, recommended, and excessive GWG in singleton pregnancies (25): the IOM recommends a GWG of 12.5–18.0 kg for underweight women, 11.5–16.0 kg for normal-weight women, 7.0–11.5 kg for overweight women, and 5.0–9.0 kg for obese women. In accordance with the interactions observed in the linear regression models, logistic regression models were further stratified by smoking and parity (at the same time removing these 2 variables from the model equations as confounders). In this case, the extreme upper limit of JPR had to be set to 25%, because this was shown to be the lowest JPR achievable in specific subgroups.

The resulting optimal GWG ranges were compared with the median, interquartile range, and the fifth and 95th percentiles of the actual GWG distribution in each subgroup, depicted by superimposed box plots.

For each maternal BMI group, we compared mean values of Apgar score (5 min after delivery) and umbilical cord arterial blood pH within the optimal GWG ranges determined by our study (as determined in the models and without stratification for parity and smoking) and as recommended by the IOM. Likewise, we compared the rates of emergency cesarean deliveries, stillbirths, and neonatal deaths in the first 7 d.

Data management and extraction were performed with SAS, version 9.1 (SAS Institute Inc, Cary, NC). All calculations were carried out with the open-source software R, version 2.6.0 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Maternal and neonatal characteristics for complete cases are shown in Table 1. The proportions of both SGA and LGA children were slightly <10%. Primiparae showed a significantly (P < 0.05) higher proportion of SGA offspring, compared with multiparae (10.9% compared with 6.4%), and a significantly lower proportion of LGA offspring, compared with multiparae (6.1% compared with 12.0%).

No considerable differences between pregnancies of complete cases compared with pregnancies of women with unknown
TABLE 1
Mature singleton deliveries ($n = 177,079$) in obstetric units in Bavaria, Germany, from 2004 to 2006: maternal and child characteristics

<table>
<thead>
<tr>
<th>Values</th>
</tr>
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<tbody>
<tr>
<td>Birth weight (g)</td>
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<tr>
<td>Weight gain in pregnancy (kg)</td>
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<tr>
<td>Gestational age at booking (completed wk)</td>
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<tr>
<td>Maternal BMI (kg/m$^2$)</td>
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<tr>
<td>Maternal height (cm)</td>
</tr>
<tr>
<td>Maternal age (y)</td>
</tr>
<tr>
<td>Gestational age (completed wk)</td>
</tr>
<tr>
<td>Apgar score after 5 min</td>
</tr>
<tr>
<td>Umbilical cord arterial blood pH</td>
</tr>
<tr>
<td>Female sex (%)</td>
</tr>
<tr>
<td>German country of origin (%)</td>
</tr>
<tr>
<td>Maternal smoking during pregnancy (%)</td>
</tr>
<tr>
<td>Primiparous pregnancies (%)</td>
</tr>
<tr>
<td>SGA (%)</td>
</tr>
<tr>
<td>LGA (%)</td>
</tr>
<tr>
<td>Emergency cesarean deliveries (%)</td>
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<tr>
<td>Stillbirths (%)</td>
</tr>
<tr>
<td>Deaths in first 7 d of life (%)</td>
</tr>
</tbody>
</table>

$^1$ SGA, small-for-gestational-age (<10th birth weight percentile); LGA, large-for-gestational-age (>90th birth weight percentile).

$^2$ Mean ± SD (all such values).

smoking status were observed in GWG, birth weight, or maternal BMI (data not shown). GWG and all confounders (sex, parity, gestational age, maternal age, maternal BMI, smoking, foreign country of origin, and single-parent status) were highly significant ($P < 0.0001$) predictors of birth weight in a linear regression model without interaction terms (Table 2). There were significant bivariate interactions for GWG with maternal BMI, smoking, and parity ($P < 0.01$), whereas no significant GWG interactions were shown with sex, gestational age, maternal age, foreign country of origin, or single parent status (data not shown).

In all logistic regression models for SGA and LGA, an increase in GWG was associated with a decrease in the predicted risk of SGA and an increase in the predicted risk of LGA. Estimated JPRs of ≤ 20% were observed for GWG values between 8 and 25 kg in underweight women and between 2 and 18 kg in normal-weight women (Figure 1). Overweight and obese women achieved JPRs of ≤ 20% with GWG values between −7 and 12 or −15 and 2 kg, respectively. The “optimal” GWG ranges were considerably wider and, particularly for obese mothers, lower than corresponding IOM categories.

DISCUSSION

The patterns of the JPRs differed largely by parity and smoking within each BMI category (Figure 2). In normal-weight primiparae, for example, the optimal GWG range was 10–26 kg for nonsmokers compared with 23–27 kg for smokers. In general, smokers showed an increased risk of delivering an SGA child, and the intervals of optimal GWG for smokers tended to be higher than those for nonsmokers. GWG interval widths for nonsmokers were ≥9 kg GWG and exceeded those of smoking mothers (except for underweight women). Although nonsmokers in each BMI category achieved JPRs of ≤ 20%, this was not observed for smoking overweight or obese mothers. Primiparous smoking obese mothers were able to achieve a JPR of 25% with a GWG of only 16 kg, whereas their JPR was 26% with a GWG of 13–20 kg.

The IOM criteria agreed relatively well with the optimal ranges for nonsmokers; however, considerable departures were noted for almost all subgroups of smokers. With the exception of obese multiparae, the optimal GWG intervals for mothers who smoked were considerably higher than those suggested by the IOM.

The box plots of the GWG distributions overlapped largely with optimal GWG ranges for nonsmokers in each subgroup apart from obese multiparae. Larger differences were shown, in particular, for smoking primiparous and/or underweight mothers. Mean values of Apgar scores and pH values, as well as rates of emergency cesarean deliveries, stillbirths, and neonatal deaths for the optimal GWG ranges determined by our study (from the models with and without stratification for parity and smoking) and as recommended by the IOM, are shown in Table 3. For the different GWG ranges, total mean values and proportions were almost identical with respect to all outcomes except for emergency cesarean delivery rates: mothers within the optimal GWG ranges determined by maternal BMI categories showed only a slightly lower emergency cesarean delivery rate (10.7%) than those within the recommended IOM ranges (11.1%) or within optimal ranges when maternal smoking and parity were considered (12.5%).

Comparison with IOM recommendations

Although others have criticized the IOM criteria from 1990 (22), which are similar to the recently published criteria (25), for being too liberal (26), our findings suggest that much wider ranges may be tolerated with respect to extreme birth weight outcomes. For overweight and obese women, we observed that...
low GWG and even gestational weight loss might be beneficial in this regard. Our results are in accordance with those of Nohr et al (21), who concluded that “underweight women may gain weight rather freely,” whereas “heavier women may be wise to avoid a high or very high GWG,” and with those of Oken et al (27), who suggested that gestational weight loss might be beneficial for overweight and obese mothers’ offspring. However, our data indicate that within subgroups, specific (and occasionally even narrower) recommendations might be needed. Women who smoke might require considerably more GWG than recommended previously, with the exception of overweight and obese smoking multiparae. Because these data are observational, however, a strong recommendation for higher GWG in this subgroup would require better confirmation in a randomized trial, whereas a recommendation to avoid smoking in pregnancy is self-evident.

Furthermore, we detected significant effect modifications of parity on the association between GWG and birth weight. Primiparae showed a considerably higher risk of SGA deliveries than did multiparae and a lower risk of LGA deliveries. Therefore, adjustment simply for parity as done in comparable studies (13, 14, 21, 28) might not be sufficient to consider the true effect of parity in the process.

In the subgroup analyses of our study, gestational weight loss appeared to be advantageous only for multiparous overweight and obese nonsmokers, whereas primiparous smokers in corresponding overweight and obese BMI categories were seen to profit from GWGs of 14 and 15 kg, respectively. It is possible that the recommendations of Kiel et al (14) for pregnancy weight loss in very obese women (BMI ≥ 40) might need to be redefined.

**Optimal birth weight compared with other perinatal outcomes**

It may be argued that the outcome of SGA is of bigger concern (at least for the child) than is the outcome of LGA. However, both outcomes have been treated as of equal interest in previous studies (13, 14, 21, 28). Other studies examined the effect of GWG on the cumulative risk of neonatal and maternal outcomes (13, 14, 28). The outcomes considered in these studies were neither mutually exclusive nor weighted by level of severity, which complicates the interpretation of these results. Interestingly, in the study on obese women by Kiel et al (14), the minimal risk of all outcomes examined was shown to be where the risks of SGA and LGA births intersected. Likewise, SGA and LGA risks were almost equal in the optimal GWG range for normal-weight women as recommended by DeVader et al (13). In comparison with the IOM intervals, optimal GWG ranges on the basis of our data, with and without consideration of effect modification by parity and smoking, developed to minimize the combined risk of SGA and LGA, did not increase the risks of all other adverse short-term delivery outcomes considered.

Unfortunately, we were unable to examine the effects on long-term outcomes such as maternal weight retention or offspring’s overweight. However, these outcomes have been shown in previous studies to be associated with elevated values of GWG (21, 28, 29). According to our results, only underweight women might

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**FIGURE 1.** Predicted risk of small-for-gestational-age (SGA) and large-for-gestational-age (LGA) births (separate as well as joint) by gestational weight gain (GWG) as calculated by logistic regression models (n = 177,079) and stratified by maternal BMI. The horizontal lines represent the joint predicted risk (JPR) limit of 20%. The vertical gray (dashed) lines represent the GWG associated with a JPR of ≤ 20%.
benefit from gaining more weight than recommended by the IOM. For these women, weight retention after pregnancy would not be a major problem.

Strengths and limitations

A major strength of the presented data results directly from the large number of pregnancies and neonates available for analysis. The data were collected for purposes not related to the study hypothesis. Data quality is high because completeness of the data sets is monitored annually across obstetric units as an integral part of benchmarking health care provision.

The calculation of GWG on the basis of weight at booking as a surrogate of prepregnancy weight, if booking occurred before the 14th week of gestation, may be seen as a limitation of our study. However, this definition of GWG has been used in a similar study (28) and is justified by the generally low GWG during the first trimester (30).

It may also be somewhat surprising that the actual proportions of SGA and LGA observed in the data set were both slightly <10% (Table 1). To define SGA and LGA, we used the most recent German reference percentiles for birth weight, derived from a data set for all German deliveries in 1992 (23). Generally, one may dispute whether maximum cumulative predicted risks of 20% or 25% of the occurrence of either SGA or LGA are appropriate cutoffs for defining optimal GWG. Justification for these thresholds, however, is derived from the consideration that, although 20% is the a priori expected risk of either SGA or LGA by definition, the alternative limit of 25% was defined by the minimal achievable JPR in any of the subgroups stratified by maternal BMI or additionally by parity and smoking in pregnancy. A definition of a “desirable” JPR of 18% on the basis of the actual observed proportions of SGA and LGA (=9% each; Table 1), for example, would not have resulted in considerably narrower optimal GWG ranges for underweight and normal-weight women (10–24g and 4–16 kg, respectively). Overweight women would be able to achieve a JPR of 18% with a GWG of ~4 to 9 kg, whereas obese women would have to lose 3–9 kg during their pregnancy.

Definitions of optimal GWG may require even further stratification with regard to complications during pregnancy and maternal pathology, such as gestational diabetes, diabetes mellitus, or preeclampsia. Exclusion of these conditions may limit the extendability of our findings. In addition, the mother’s ethnicity may need to be considered, because different optimal GWG ranges were reported for Chinese compared with white women (31). A further limitation regarding generalizability of our results pertains to premature births, because these were excluded. Premature birth, however, is difficult to predict.

The potential of minimizing the risk of poor perinatal outcomes by optimizing GWG, however, is ultimately limited, because the effect of GWG on optimal birth weight is small and depends also on the presence or absence of other risk factors. Although GWG was a highly significant predictor of birth weight in the linear regression model, it only accounted for an increase of 17.7 g in birth weight per 1 kg GWG (Table 2). By contrast, children of multiparous women were, on average, 143.7 g heavier at birth than first-borns. Such an increase would require an increase of ~8 kg in GWG. A difference of 186.8 g was shown between birth weights of children born to nonsmoking and
Deaths within the first 7 d of life (%)

<table>
<thead>
<tr>
<th>MBMI</th>
<th>P+S</th>
<th>IOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>10.7 (0.2)</td>
<td>12.5 (0.2)</td>
</tr>
<tr>
<td>Underweight</td>
<td>9.5  (0.7)</td>
<td>9.6  (0.8)</td>
</tr>
<tr>
<td>Normal weight</td>
<td>10.7 (0.2)</td>
<td>11.6  (0.2)</td>
</tr>
<tr>
<td>Overweight</td>
<td>11.5 (0.5)</td>
<td>15.5  (0.5)</td>
</tr>
<tr>
<td>Obese</td>
<td>12.1 (1.9)</td>
<td>20.1  (1.2)</td>
</tr>
</tbody>
</table>

Stillbirths (%)

| Total      | 0.09 (0.02) | 0.09 (0.02) | 0.10 (0.02) |
| Underweight| 0.00 (0.00) | 0.00 (0.00) | 0.00 (0.00) |
| Normal weight | 0.09 (0.02) | 0.09 (0.02) | 0.08 (0.03) |
| Overweight | 0.11 (0.05) | 0.09 (0.04) | 0.13 (0.07) |
| Obese      | 0.43 (0.37) | 0.27 (0.15) | 0.28 (0.14) |

Emergency cesarean deliveries (%)

| Total      | 7.30 (0.00) | 7.28 (0.00) | 7.29 (0.00) |
| Underweight| 7.29 (0.00) | 7.29 (0.00) | 7.29 (0.00) |
| Normal weight | 7.29 (0.00) | 7.28 (0.00) | 7.29 (0.00) |
| Overweight | 7.29 (0.00) | 7.28 (0.00) | 7.29 (0.00) |
| Obese      | 7.30 (0.00) | 7.28 (0.00) | 7.29 (0.00) |

Umbilical cord arterial blood pH

| Total      | 7.29 (0.00) | 7.29 (0.00) | 7.29 (0.00) |
| Underweight| 7.29 (0.00) | 7.29 (0.00) | 7.29 (0.00) |
| Normal weight | 7.29 (0.00) | 7.28 (0.00) | 7.29 (0.00) |
| Overweight | 7.29 (0.00) | 7.28 (0.00) | 7.29 (0.00) |
| Obese      | 7.30 (0.00) | 7.28 (0.00) | 7.29 (0.00) |

Apgar score (at 5 min after birth), umbilical cord arterial blood pH, and rates of emergency cesarean deliveries, stillbirths, and deaths in the first 7 d of life in mothers with “optimal” gestational weight gain.


gestational weight gain and birth weight


table 3

<table>
<thead>
<tr>
<th>MBMI</th>
<th>P+S</th>
<th>IOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>9.79 (0.00)</td>
<td>9.78 (0.00)</td>
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<tr>
<td>Underweight</td>
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<td>Normal weight</td>
<td>9.79 (0.00)</td>
<td>9.79 (0.00)</td>
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<tr>
<td>Overweight</td>
<td>9.79 (0.01)</td>
<td>9.77 (0.01)</td>
</tr>
<tr>
<td>Obese</td>
<td>9.72 (0.05)</td>
<td>9.71 (0.02)</td>
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