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Optimal gestational weight gain: Prepregnancy BMI specific influences on adverse pregnancy and infant health outcomes

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Abstract

BACKGROUND—The Institute of Medicine (IOM) 2009 gestational weight gain (GWG) guidelines are based on prepregnancy body mass index (BMI) categories. We intended to refine optimal GWG for each prepregnancy BMI unit in relation to the risk of small- and large-for-gestational-age (SGA and LGA) births, cesarean section (C-section), and infant death.

METHODS—We used data from 836,841 Ohio birth records from 2006 to 2012, and applied generalized additive models to calculate optimal GWG by prepregnancy BMI unit.

RESULTS—The suggested optimal GWG was generally similar to IOM 2009 GWG guidelines for prepregnancy BMIs <25 kg/m^2, but higher for prepregnancy BMIs 25–32 kg/m^2 and lower for BMIs 38–50 kg/m^2. The suggested optimal GWG was 14–18.5, 13–17, 11.5–16, 8.5–12.5, 4–10, 3–7, 1.5–6, and 1.5–4.5 kg for prepregnancy BMIs 15, 20, 25, 30, 35, 40, 45, and 50 kg/m^2, respectively.

CONCLUSION—This research suggests that GWG recommendations may be refined at individual prepregnancy BMI levels.

Gestational weight gain (GWG) is a modifiable factor during the entire course of pregnancy that may be utilized to improve pregnancy outcomes.[1, 2] Prepregnancy body mass index (BMI) is a determinant of GWG and is also the basis for the Institute of Medicine (IOM) GWG guidelines. The IOM 2009 GWG guidelines are 12.5–18, 11.5–16, 7–11.5, and 5–9 kg

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Conflict of interest

The authors declare no conflict of interest.

for underweight, normal weight, overweight, and obese pregnant women, respectively.[1] The categorical guidelines are relatively straightforward in providing clinicians GWG recommendations that are memorable to pregnant women.[3] Despite the advantages, the current guidelines do not take into account variability of BMI within each category. For example, a woman with a prepregnancy BMI of 31 kg/m^2 is recommended to gain the same range of weight as a woman with a prepregnancy BMI of 41 kg/m^2. Further, the guidelines have rather different recommendations for women with prepregnancy BMIs that fall into neighboring weight categories, but with relatively small differences in BMI values. This is particularly evident in the upper band of normal weight and the lower band of overweight BMIs as the current GWG guidelines for these two groups barely overlap. For example, a woman with a prepregnancy BMI of 24 kg/m^2 receives a current GWG recommendation of 11.5–16 kg, while a woman with a prepregnancy BMI of 26 kg/m^2 is recommended to gain 7–11.5 kg. These limitations may call for refined recommendations of GWG based on finer prepregnancy BMI groups or even better, based on each prepregnancy BMI integer value (unit of 1 kg/m^2). We attempted to examine the possibility of developing prepregnancy BMI unit-specific GWG recommendations using population-based birth data, which may yield better granularity in the GWG guidelines to achieve a more “personalized” recommendation for pregnant women.

Methods

We used statewide birth certificate and linked death certificate data in Ohio from 2006–2012 to examine the relation of prepregnancy BMI and GWG and four adverse pregnancy and infant outcomes. The sample size was 836,841 (81.1%) out of a total of 1,031,259 live birth records, after restricting to singleton live births at 22–44 weeks of gestation, with birth weight 350 to 6000 g, prepregnancy BMI 15–50 kg/m^2, GWG within −5 to 30 kg, and weekly weight gain during the 2nd and the 3rd trimesters (Trimesters 2&3 weekly GWG) within −0.2 to 1 kg/wk.[4] These restrictions were likely to remove extreme values in weekly GWG and make the findings more generalizable. We obtained Institution Review Board (IRB) approvals from the Ohio Department of Health and the University of Cincinnati for the study.

On the birth certificates, maternal prepregnancy weight, maternal height, and maternal weight before delivery were recorded. Maternal prepregnancy BMI (kg/m^2) was calculated as the prepregnancy weight in kilogram divided by the square of maternal height (meter). Maternal GWG (kg) was calculated by subtracting maternal prepregnancy weight from maternal weight at delivery. The validity of the weight and height information on birth certificate has been evaluated in other states, suggesting overall good precision but with some misreporting.[4, 5, 6] Trimesters 2&3 weekly GWG was calculated by subtracting first trimester GWG (assuming 2 kg for non-obese women and 1.5 kg for obese women according to literature) from total GWG and then dividing by gestational weeks in the 2nd and the 3rd trimesters.[3] As the total GWG varies significantly by gestational age at birth, we preferred to use Trimester 2&3 weekly GWG over total GWG in studying optimal GWG and adverse pregnancy and infant outcomes. In sensitivity analysis, however, we also used total GWG as an independent variable to verify the findings and found the final interpretation would be similar to the use of Trimester 2&3 weekly GWG. Therefore, we only report the findings based on Trimester 2&3 weekly GWG.

Adverse pregnancy outcomes and complications related to prepregnancy BMI and GWG include preterm birth, low birth weight, small-for-gestational-age (SGA), large-for-gestational-age (LGA), cesarean section delivery (C-section), pregnancy-induced hypertension (encompassing gestational hypertension and preeclampsia not superimposed on chronic hypertension), and gestational diabetes.[1] Infant mortality is also modified by prepregnancy BMI and GWG.[7] As we attempt to minimize the impact of gestational age in modeling, we chose outcome variables that can be standardized by gestational age or not impacted by reverse causation in which medical condition may affect GWG (e.g., gestational diabetes or hypertension).[8] We finally used SGA and LGA to indicate fetal growth, C-section to indicate delivery option and medical cost, and infant death to represent critical postnatal health status. The use of four pregnancy and infant health outcomes allowed us an opportunity to balance the probabilities of these outcomes in search of prepregnancy BMI unit-specific optimal GWG. SGA was defined as birth weight <10th percentile of a sex- and gestational-age-specific birth weight reference in the US, and LGA was defined as birth weight >90th percentile of the same reference.[9] C-section was reported on the birth certificate, and infant death (between 0–365 days) was reported on death certificate linkable to birth record (though only linkable for births from 2007 to 2012 as 2006 death certificate lacked such link).

We used generalized additive model (GAM) to generate a non-linear smooth 3D surface plot that had SGA, LGA, C-section, and infant death (modeled separately, and infant death model only among 2007–2012 births [n=714,232]) as the dependent variable. The 3D surface incorporates two predictive factors (prepregnancy BMI and weekly GWG for the second and third trimesters), but in one smoothing item (s[BMI, weekly GWG for trimesters 2&3], s is the smoothing function).[10, 11] The smoothing item accounts for related predictive factors as well as their interaction. We adjusted *a priori* for maternal age, race, education, smoking, marital status, enrollment in Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), Kotelchuck's adequacy of prenatal care utilization (APNCU) index,[12] and 2013 census-based National Center for Health Statistics Urban-Rural Classification Scheme for Counties,[13] infant sex, live birth order, and birth year in the regression models to account for possible confounding by covariates that may affect prepregnancy BMI, weekly GWG, and adverse pregnancy and infant health outcomes.[14, 15, 16]

Based on the predictive models, we further explored the optimal GWG at each prepregnancy BMI unit by calculating Trimesters 2&3 weekly GWG to meet the criteria of reducing the probabilities of adverse pregnancy outcomes to a target set of proportions with regard to current event percentage: 100%, 95%, 90%, 85%, and 80%. This set meant to provide a range of Trimesters 2&3 weekly GWG for expert decision making (even after publication). For SGA and infant death, we had a set of minimum GWG because GWG below that threshold would increase the risk. For LGA and C-section, we had a set of maximum GWG because GWG above that threshold would increase the risk. Although determining optimal GWG for each prepregnancy BMI unit involved both modeling and arbitration, we attempted to: 1) for prepregnancy BMIs in the underweight range, keep the maximum allowable risks of SGA and infant death lower than current level while slightly reducing maximum allowable risks for LGA and C-section below current levels; 2) for prepregnancy BMIs in normal weight, overweight, and obesity range, keep maximum allowable risks of LGA and C-section lower and close to 80% of current percentages if possible while slightly reducing maximum allowable risks for SGA and infant death below current levels; 3) maintain a wider optimal Trimesters 2&3 weekly GWG range if applicable (to include more women within the GWG range); 4) use current IOM GWG guidelines as a reference while not bound by the recommendations. We used SAS 9.4 (SAS Institute Inc., Cary, NC) for general statistical analysis and R 3.3.0 mgcv 1.8–12 package (R Core Team, Vienna, Austria) for GAM and graphing.[17]

Code availability: the computational codes are available by contacting the corresponding author.

Results

The mean prepregnancy BMI in the sample of 836,841 pregnant women was 25.99 (Standard deviation [SD] 6.21) kg/m^2, and the mean Trimesters 2&3 weekly GWG was 0.45 (SD 0.23) kg/wk (Table 1). The proportions of SGA, LGA, C-section, and infant death were 10.37%, 7.24%, 28.18% and 0.47%, respectively. About 81% of pregnant women were white, 16% were black in the study data. The prevalence of maternal smoking during pregnancy was 18.6%, and the percentage of women on WIC nutrition supplementation program was 41.6%.

The logit function of predicted probabilities of SGA, LGA, C-section, and infant death and prepregnancy BMI and Trimesters 2 & 3 weekly GWG is shown in Figure 1. The smoothed 3D plots depict a trend of reduced SGA probability by increased prepregnancy BMI and increased Trimesters 2 & 3 weekly GWG. In contrast, the probabilities of LGA and C-section increase with increased prepregnancy BMI and Trimesters 2 & 3 weekly GWG. The probability of infant death increased with prepregnancy BMI and showed a trend of reduction with increasing Trimester 2 & 3 weekly GWG.

The predicted probabilities of SGA, LGA, C-section, and infant death by Trimesters 2 & 3 weekly GWG at prepregnancy BMI of 25 kg/m^2 are shown in Figure 2 as an example. The figures at other prepregnancy BMI values are available upon request. These 2D graphs provide direct readings of predicted probabilities of adverse pregnancy and infant health outcomes by changes in weekly GWG at each prepregnancy BMI unit, which can be used to pinpoint optimal GWG for that prepregnancy BMI value.

The calculated minimum Trimesters 2 & 3 weekly GWG for predicted SGA risk at 100%, 95%, 90%, 85%, and 80% of current levels for each prepregnancy BMI unit is shown in Supplemental Table 1S. Similarly, the calculated maximum Trimesters 2 & 3 weekly GWG for predicted LGA and C-section risk at variants of current levels for each prepregnancy BMI unit is shown in Supplemental Tables 2S and 3S, respectively. Supplemental Table 4S shows the minimum Trimesters 2&3 weekly GWG for predicted infant death risk at variants of current levels.

Figure 3 shows the suggested optimal Trimesters 2&3 weekly GWG for each prepregnancy BMI unit after considering predicted SGA, LGA, C-section, and infant death risks by weekly GWG variations. The optimal Trimesters 2&3 weekly GWG ranges from this research (in red) were shown along with current IOM weekly GWG recommendations (in blue) on the backdrop of weekly GWG distribution box-and-whisker plots in this research dataset. The corresponding optimal total GWG derived from Trimesters 2&3 weekly GWG was also inscribed at the bottom of the figure. The major differences between the suggested and the current IOM GWG guidelines are: a) higher Trimesters 2&3 weekly GWG at prepregnancy BMIs 25–32 kg/m^2 (e.g., 0.35–0.5 kg/wk vs. 0.23–0.33 kg/wk at BMI 25 kg/m^2), and b) lower Trimesters 2&3 weekly GWG at prepregnancy BMIs 38–50 kg/m^2 (e.g., 0.05–0.2 kg/wk vs. 0.17–0.27 kg/wk at BMI 38 kg/m^2).

Discussion

We described a novel approach to identify prepregnancy BMI unit-specific optimal GWG in relation to SGA, LGA, C-section, and infant death outcomes and provided suggested optimal GWG ranges. This analysis describes the possibility of refining IOM GWG guidelines with better precision according to women’s unit-specific prepregnancy BMI values. The suggested optimal GWG in relation to four adverse pregnancy and infant health outcomes in this analysis may not be viewed as definitive recommendations, but as a basis from which other studies can assess the influence of GWG to further refine the current IOM GWG guidelines, preferably in a larger national dataset and incorporate additional health outcomes, for example, maternal weight retention and child obesity.

This study utilized information from both prepregnancy BMI and weekly GWG in the smoothing predictor of the GAM, which incorporates non-linear associations between prepregnancy BMI, weekly GWG, and their interactions with fetal growth and infant health.[10] It offers an opportunity to generate detailed patterns of pregnancy outcomes as a function of co-variation of these related factors. GWG includes fetal weight, which is the basis to calculate SGA or LGA, but GWG is more inclusive than fetal weight (e.g., placenta, amniotic fluid, water retention, fat deposits) and is easier to measure by clinicians and pregnant women than nutrition intake and energy balance.[18] Since the issuance of IOM 2009 GWG guidelines, various efforts were taken to validate or refine the guidelines, including noninferiority margin of adverse perinatal outcomes by GWG z-score,[19] increased focus on obesity or overweight women,[15, 20, 21, 22, 23] or examining trimester-specific weight gain.[24, 25] However, no prior studies have attempted to refine the guidelines by individual prepregnancy BMI unit, even in the case that GWG was considered for prepregnancy BMIs in obesity classes I, II, and III.[21, 22] This study is probably the first attempt to refine the GWG guidelines by each unit of prepregnancy BMI after consideration of different fetal and infant health outcomes. The study findings are of value amdist thisera of an obesity epidemic, in which maternal GWG may be modifiable to benefit child health.

The approach we used to calculate optimal GWG was based on reduced probabilities for SGA, LGA, C-section, and infant death to a set criterion at any prepregnancy BMI unit. Compared with the current IOM GWG guidelines,[1] our calculated optimal GWG ranges were generally similar at prepregnancy BMIs <25 kg/m^2. For prepregnancy BMIs 25–32 kg/m^2, our calculated optimal GWG was higher than the IOM recommendations but presented better continuity over prepregnancy BMI values from 20 to 32 kg/m^2. For obese women with prepregnancy BMIs ≥38 kg/m^2, our calculated optimal GWG was mostly lower than the IOM guidelines. There could be several other options in determining optimal GWG after generating smoothed 3D surface plots. One is to provide a set of fixed maximum allowable risks of SGA, LGA, C-section, and infant death at each prepregnancy BMI unit without using a sliding scale as we used (from 100% to 80% of current) because the current risk vary by population. However, determining those cutoffs may be arbitrary too. Second is to tailor the optimal GWG for more specific subgroups (e.g., women within a certain age range or of a certain race) by changing the combination of covariates in the prediction.[3] However, these modifications may not substantially alter the optimal GWG from the calculated values.

This study has several limitations inherent to the use of vital statistics as a data source. First, validated prepregnancy weight and height were not available; nor were first trimester weight and repeated measurements of weight gain during the last two trimesters available to help validate weekly GWG. With the increasing usage of electronic medical records, prepregnancy BMI and weight gain history can be integrated into databases to provide information from a large section of the population instead of limited obstetric practice facilities. Nevertheless, prepregnancy weight and height on birth certificate may be of reasonably high quality. A validation study of prepregnancy BMI in Florida WIC program participants indicated birth certificate data under-reported weight by a mean of 1.9 kg, over-reported height by a mean of 1 cm, and under-reported BMI by 1 kg/m^2.[5] Previous validation studies of GWG were based on GWG categories;[4, 6] a simulation of Pennsylvania statewide data suggested a higher proportion of women reported a total weight gain of 10–20 kg on birth certificate data than what was recorded on medical records, with the latter having a wider total weight gain range. It also showed birth certificates had higher frequencies women reporting no increase (0 kg) in weight gain compared with medical records.[4] Therefore, prospectively measured weight data during pregnancy holds more promise in addressing the research question, but the data necessary to achieve sufficient validity and an adequate sample size would require additional time to collect. Second, the dataset we used was limited to a single state, although this does not affect our methodological approach, the findings may not be readily generalizable to the entire US. According to the National Vital Statistics, Hispanic women comprise almost a quarter of US mothers giving birth in 2011, while our dataset contained <4%.[26] Third, women may have contributed two or more pregnancies in the 7 years of study data, and we could not adjust for clustering by the same women. We also could not compare the role of GWG on birth outcomes of subsequent pregnancies in the same women if these pregnancies had different pregnancy outcomes. Fourth, the recommendation of optimal GWG should be based on various perinatal and postnatal outcomes, not limited to the four we examined.[14, 27, 28] Prepregnancy BMI unit-specific optimal GWG in relation to neonatal morbidity, other pregnancy and delivery complications, maternal postpartum weight retention, and child obesity should also be investigated in the future. Fifth, the more granular optimal GWG may appear to be cumbersome to clinicians who has yet to implement the 2009 IOM GWG guidelines into daily practice. More personalized in prenatal care, however, cannot be dismissed if GWG is deemed modifiable (evidenced by temporal trends since 1950s) and important for achieving better perinatal outcomes.[29] It is possible to develop an App for mobile devices that clinicians can use to determine optimal GWG based on combined risk of adverse pregnancy and infant health outcomes.

Despite the limitations, this research also has significant strengths. It is among the first efforts to explore the possibility of providing prepregnancy BMI unit-specific GWG guidelines in a large population using a smooth 3D surface plot. This establishes an approach that can be applicable to other maternal and child health indicators. The flexibility of adjusting the maximum allowed probability of adverse birth outcomes will make it possible to have different interpretations of optimal GWG by different experts in obstetrics, maternal and fetal medicine, nenonatology, nutrition, and epidemiology before a consensus is reached. This research may stimulate future investigations to refine GWG guidelines with better granularity.

In summary, we calculated optimal GWG for SGA, LGA, C-section, and infant death outcomes based on individual prepregnancy BMI unit. Future research may assess the GWG influences on other important perinatal and postnatal outcomes with large validated prepregnancy BMI and GWG datasets to provide “personalized” GWG to benefit mothers and children. This should not be interpreted, though, as only GWG can be modified, achieving healthy prepregnancy BMI is equally, if not more important, to reduce health burdens associated with the both ends of weight status.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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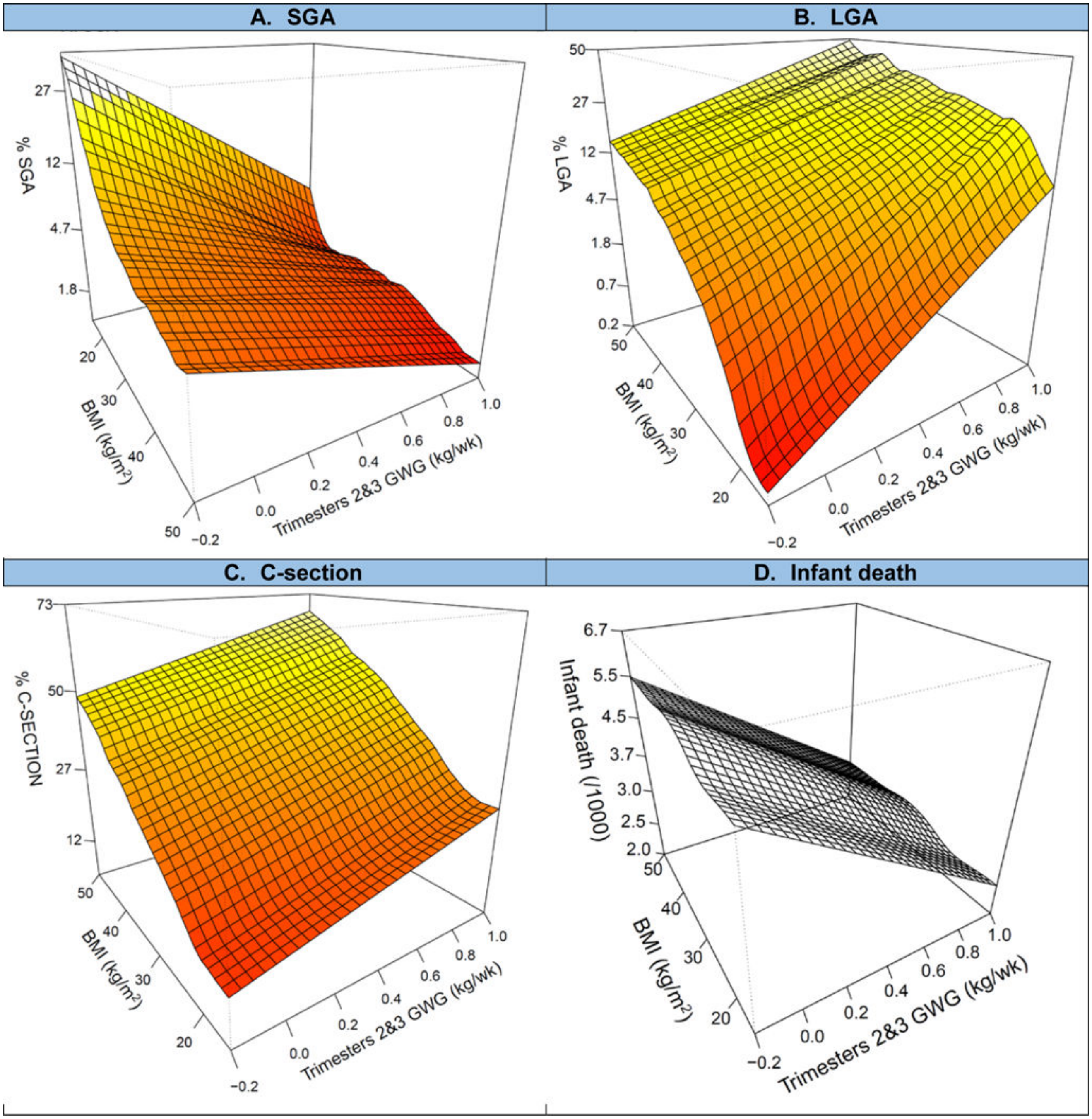

Figure 1.

Logit function of predicted probabilities of SGA, LGA, C-section, infant death by prepregnancy BMI and Trimesters 2&3 weekly GWG in 3D surface plots. The z axis labels were converted to probabilities based on their logit function values.

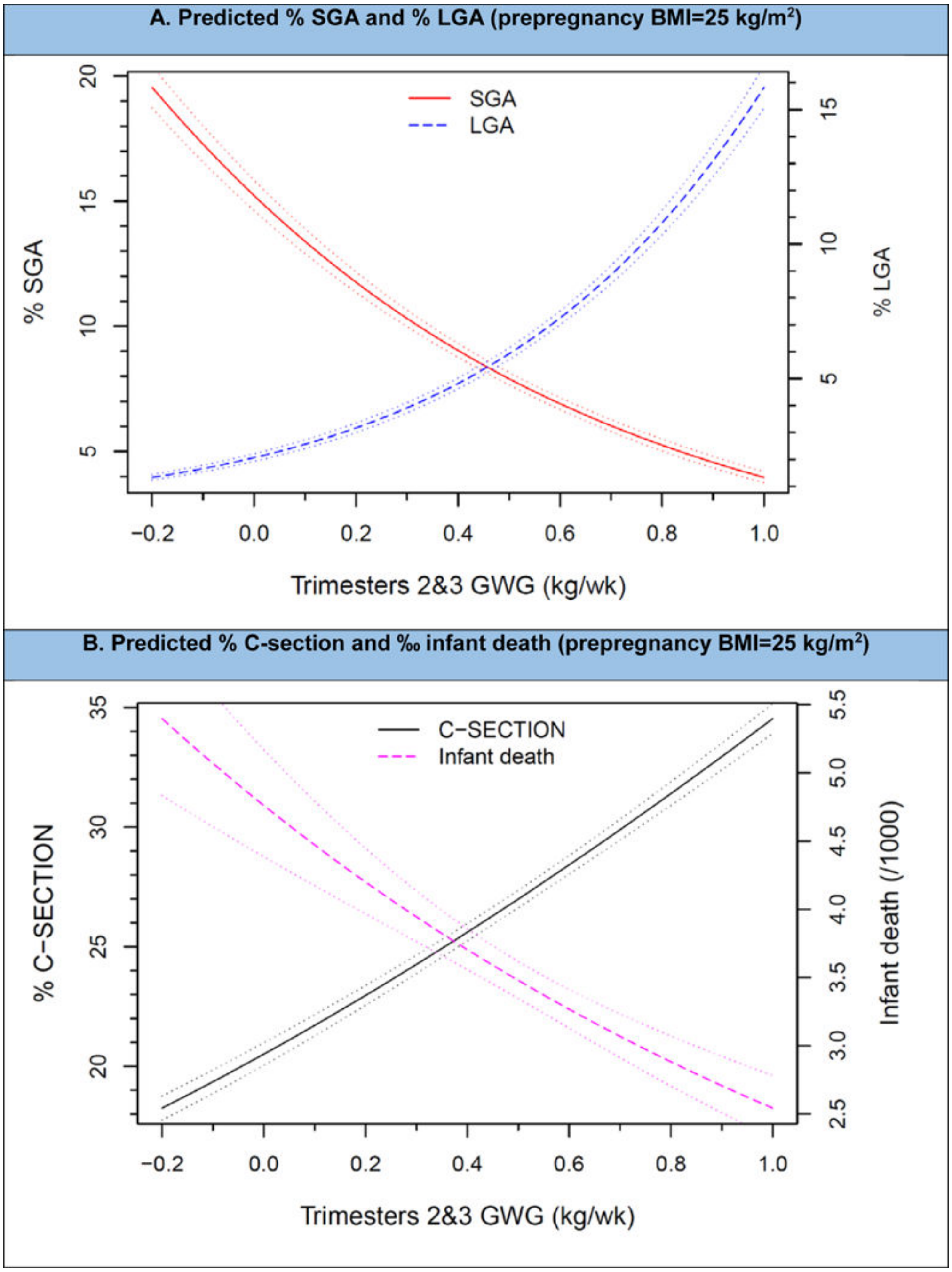

Figure 2.

Predicted probabilities of SGA, LGA, C-section, and infant death and 95% confidence intervals by Trimesters 2&3 weekly GWG at prepregnancy BMI of 25 kg/m^2.

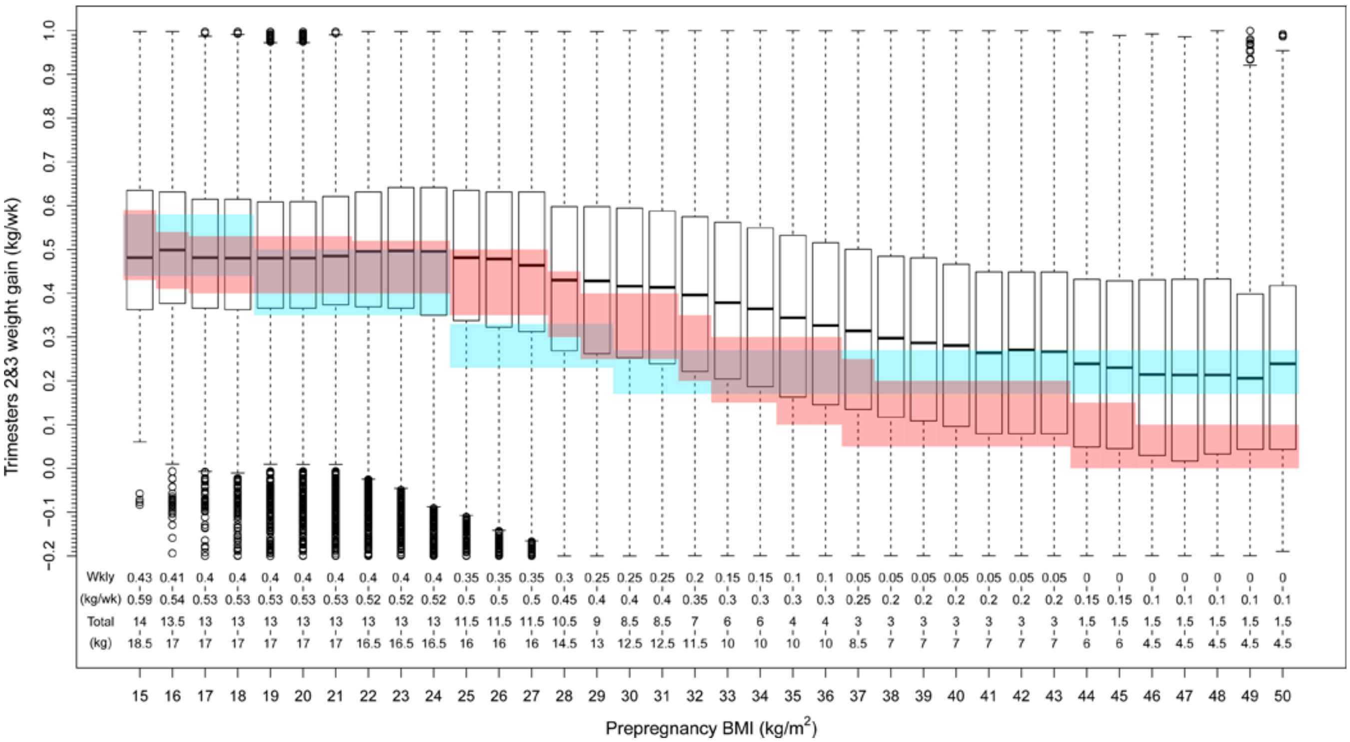

Figure 3.

Distribution of Trimesters 2&3 weekly GWG by prepregnancy BMI in box and whisker plots in the study sample. The blue shadowed area in the figure indicates the Institute of Medicine 2009 Trimesters 2&3 weekly GWG guidelines for prepregnancy underweight (0.44–0.58 kg/wk), normal weight (0.35–0.5 kg/wk), overweight (0.23–0.33 kg/wk), and obese women (0.17–0.27 kg/wk). The red shadowed area in the figure indicates the suggested Trimesters 2&3 weekly GWG from this research, with numerical values inscribed at the bottom of the figure along with the derived total GWG.

Table 1

Maternal and infant characteristics, pregnancy outcomes, and weight gain in Ohio birth data 2006–2012

Maternal and infant characteristics	**N**	**%**
Total	836,841	100
Maternal age, years		
< 20	84,058	10.04
20–24	217,073	25.94
25–29	247,722	29.60
30–34	189,248	22.61
≥35	98,728	11.80
Maternal race		
White	670,294	81.09
African American	133,966	16.21
Others	22,392	2.71
Maternal educational level		
Less than high school	135,407	16.25
High school graduate	214,370	25.73
Some college or higher	483,488	58.02
Maternal smoking		
Yes	154,471	18.56
No	677,659	81.44
Marital status		
Married	487,947	58.31
Not married	348,894	41.69
WIC enrollment		
Yes	344,990	41.57
No	484,973	58.43
Kotelchuck Index		
No prenatal care	200,908	24.01
Inadequate	108,887	13.01
Intermediate	74,899	8.95
Adequate	251,893	30.10
Adequate plus	200,254	23.93
Urbanicity		
Large central metro	255,425	31.45
Large fringe metro	164,111	20.21
Medium metro	190,780	23.49
Small metro	32,100	3.95
Micropolitan	136,542	16.81
Noncore	33,154	4.08
Infant sex		
Male	428,318	51.18

Maternal and infant characteristics	**N**	**%**
Female	408,523	48.82
Live birth order		
1	273,246	33.37
2	229,039	27.97
≥3	316,502	38.65
Year of birth		
2006	120,060	14.35
2007	123,556	14.76
2008	123,905	14.81
2009	121,412	14.51
2010	117,261	14.01
2011	114,822	13.72
2012	115,825	13.84
SGA	86,747	10.37
LGA	60,576	7.24
C-section	235,647	28.18
Infant death	3,330	0.47
Prepregnancy BMI (mean±SD, median, IQR), kg/m^2	25.99±6.21, 24.41, 21.46–29.21	
Trimesters 2&3 weekly weight gain (mean±SD, median, IQR), kg/wk	0.45±0.23, 0.46, 0.31–0.61	
Total weight gain (mean±SD, median, IQR), kg	13.97±6.32, 14.06, 9.98–18.14	