Association between mid-to-late pregnancy gestational weight gain and adverse birth outcomes among women with gestational diabetes mellitus

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Running title: Gestational weight gain and birth outcomes in GDM

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ABSTRACT

Background and Objectives: The gestational weight gain (GWG) range during mid-to-late pregnancy associated with the lowest combined risk of adverse birth outcomes in women with gestational diabetes mellitus (GDM) remains unclear. This study aims to examine the associations between GWG and adverse birth outcomes among women with GDM. **Methods and Study Design:** This study included a cohort of 1,673 pregnant women with GDM. GWG was defined as weight gain from pre-pregnancy to a measurement between 24 and 32 gestational weeks, residualized for gestational age and standardized as z-scores. Multivariable logistic regression models were used to assess associations between GWG z-scores (per 1-SD increase and categories: <-1, -1 to 1 [reference], and >1) and small for gestational age (SGA), large for gestational age (LGA), and preterm birth. Restricted cubic splines were fitted to explore nonlinear associations. **Results:** Each 1-SD higher in GWG z-score was associated with lower odds of SGA (odds ratio [OR], 0.55; 95% confidence interval [CI], 0.43-0.71) and higher odds of LGA (1.48; 1.29-1.70). Compared with the reference group, women with GWG z-scores <-1 had higher odds of SGA and lower odds of LGA, whereas those with z-scores >1 showed the opposite pattern. No significant association was observed with preterm birth. Spline analyses indicated that a GWG z-score of approximately -0.07 (equal to 8.2 kg at 28 weeks) was associated with the lowest combined odds of SGA and LGA. **Conclusions:** Among women with GDM, both insufficient and excessive mid-to-late pregnancy GWG were associated with adverse size-for-gestational-age outcomes.

Key Words: gestational diabetes mellitus, gestational weight gain, small for gestational age, large for gestational age, birth outcomes

INTRODUCTION

Gestational weight gain (GWG) is a key modifiable factor during pregnancy and has been consistently associated with a wide range of birth outcomes.[1,2] Evidence from observational studies suggests that insufficient GWG is associated with a higher risk of small for gestational age (SGA) and preterm birth, whereas excessive GWG is associated with a higher risk of large for gestational age (LGA) and caesarean delivery,[3,4] underscoring the importance of appropriate weight management during pregnancy. Based on evidence from population-based studies, clinical guidelines such as those issued by the Institute of Medicine (IOM) have proposed recommended total GWG and suggested rates of weight gain during the second and third trimesters for the general obstetric populations.[5] However, their applicability to women

with gestational diabetes mellitus (GDM)-who differ in metabolic risk and fetal growth patterns-has not been fully established due to limited research evidence.

Previous studies have investigated GWG targets for women with GDM using different exposure frameworks. Several studies have focused on total GWG across pregnancy, either examining adherence to guideline-based categories or estimating cumulative weight gain ranges that were associated with lowest odds of adverse birth outcomes.[6-14] While these studies contribute to the understanding of overall GWG targets in GDM pregnancies, total GWG can only be fully determined at delivery, which may limit its utility for timely clinical intervention during pregnancy. To improve clinical relevance, other research has characterized GWG as a rate of weight gain across the second and third trimesters, and propose GDM-specific weekly gain targets that outperform general recommendations.[15] However, averaging weight gain across an extended gestational period may obscure heterogeneity in weight gain patterns between mid- and late-pregnancy which differs substantially in metabolic demands and fetal growth trajectories.[16,17] Consequently, the associations between weight gain during more specific and potentially actionable windows of mid-to-late pregnancy and adverse birth outcomes in women with GDM remain inconclusive.

To address these gaps, we utilized data a prospective birth cohort of women with GDM, to examine associations between gestational weight gain during mid-to-late pregnancy (24–32 weeks of gestation) and the risk of adverse birth outcomes, including SGA, LGA, and preterm birth. We further assessed GWG ranges corresponded to lower odds of adverse birth outcomes. This study aims to contribute evidence relevant to refining GWG management considerations for women with GDM.

MATERIALS AND METHODS

Study population

The Westlake Precision Birth Cohort (WeBirth) is an ongoing prospective cohort study among women with GDM and their offspring living in Hangzhou, China.[18] Participant recruitment was initiated in August 2019. Pregnant women aged 18 years or older who were diagnosed with GDM were enrolled at their first clinic visit. Key exclusion criteria included a history of cancer or other severe chronic diseases. All participants received routine prenatal care and health counseling as recommended by their clinicians.

As part of standard prenatal care, a 2-hour 75-g oral glucose tolerance test (OGTT) was administered between 24 and 28 weeks of gestation. GDM was defined according to the International Association of Diabetes and Pregnancy Study Groups (IADPSG) criteria as

fasting plasma glucose ≥5.1 mmol/L, and/or 1-hour plasma glucose ≥10.0 mmol/L, and/or 2-hour plasma glucose ≥8.5 mmol/L.19 During follow-up, maternal blood pressure, body weight, continuous glucose monitoring data, and other clinical measurements were routinely collected. Information on birth outcomes, including gestational age at delivery, birth weight, birth length, and perinatal medical records, was obtained from the electronic medical records of the prenatal care and delivery clinics. Demographic characteristics and lifestyle factors were collected using standardized questionnaires administered by trained staff during face-to-face visits. The study was approved by the Ethics Committee of Westlake University (20190701ZJS0007). Written informed consent was obtained from each participant.

For the present analysis, a total of 2001 women with GDM were initially identified. We excluded 186 participants with missing infant birth weight data and 136 participants with missing information on gestational weight gain between 24 and 32 weeks of gestation. An additional six participants with implausible weight change values (<-2 kg) during this period were excluded (Supplementary Figure 1). The final analytic sample consisted of 1673 pregnancies.

Exposures

Gestational weight gain (GWG) during mid-to-late pregnancy was defined as the difference between measured maternal weight at 24–32 weeks of gestation and pre-pregnancy weight. To account for gestational age–related variation in weight gain, GWG was regressed on gestational age (in weeks) using a linear model, and individual residuals were obtained. Individual-level residuals from this model were then derived to represent deviations from the expected GWG trajectory conditional on gestational age. These residuals were standardized by converting them into z-scores based on the distribution of residuals at the corresponding gestational week. The resulting gestational age-specific residual z-scores were used as the primary exposure variable. This method allows for accurate comparisons between individuals, adjusting for the inherent heterogeneity in weight gain at different gestational weeks. The GWG z-scores were analyzed both as a continuous variable and as a categorical variable classified into three groups: < -1, -1 to 1, and ≥1, reflecting relatively lower, average, and higher GWG compared with the gestational age‑specific expectation.

Covariates

Maternal age (years), pre-pregnancy body mass index (BMI, kg/m²), and parity (nulliparous vs. multiparous), fasting blood glucose (FBG), total cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (HDL-C) were included as covariates in all multivariable models.

Outcomes

The primary outcomes of this study were small for gestational age (SGA), large for gestational age (LGA), and preterm birth. Birth weight and gestational age at delivery were obtained from medical records. SGA and LGA were defined as birth weight below the 10th percentile and above the 90th percentile, respectively, for gestational age and sex, according to the Chinese Growth Standard for Newborns by Gestational Age.[20] Preterm birth was defined as delivery before 37 completed weeks of gestation. All outcomes were treated as binary variables in the analyses.

Statistical analyses

Baseline characteristics of the study population were summarized overall and according to categories of gestational weight gain (GWG) z-scores (< -1, -1 to 1, and ≥1). Continuous variables were presented as means (standard deviations) or medians (interquartile ranges), as appropriate, and categorical variables were presented as counts and percentages. Group differences were assessed using analysis of variance (ANOVA) for normally distributed continuous variables and the Kruskal-Wallis test for non-normally distributed continuous variables, chi-square tests were used for categorical variables.

Logistic regression models were used to examine the associations between GWG z-scores during mid-to-late pregnancy and adverse birth outcomes, including SGA, LGA, and preterm birth. GWG z-scores were primarily analyzed as a continuous variable (per 1-SD increase) to assess the overall association with each outcome. In addition, GWG z-scores were categorized (< -1, -1 to 1 [reference], and ≥1) for descriptive and interpretative purposes, and these analyses were considered secondary. Crude models were first fitted without covariate adjustment. Multivariable models were then adjusted for maternal age, pre-pregnancy BMI, parity, FBG, TC, TG, LDL-C, HDL-C.

Prespecified subgroup analyses were conducted to assess the robustness of associations across key maternal and infant characteristics, including maternal age (<35 vs. ≥35 years),

pre-pregnancy BMI (<18.5, 18.5-23.9, and ≥24.0 kg/m²), parity (nulliparous vs. multiparous), and infant sex. The consistency of associations across subgroups was evaluated by including interaction terms between GWG z-scores and subgroup variables in the models.

Sensitivity analyses were performed to evaluate the robustness of the findings. These included further adjustment for maternal education level and household income; exclusion of participants with extreme GWG z-scores (absolute value >3); exclusion of women with hypertensive disorders of pregnancy; and exclusion of pregnancies complicated by other adverse birth outcomes. Results from sensitivity analyses were compared with those from the primary analyses for consistency.

To explore potential non-linear associations between GWG z-scores and the risk of LGA, restricted cubic spline models were fitted with knots placed at prespecified percentiles of the z-score distribution. Odds ratios (ORs) and corresponding 95% confidence intervals were estimated across the range of z-scores using predictions derived from the fitted restricted cubic spline models, with a z-score of zero as the reference. Based on the spline curves, GWG z-score intervals corresponding to OR thresholds of 1.0, 1.2, and 1.5 were prespecified to define different association ranges. Given the opposing directions of association between GWG z-scores and the odds of SGA and LGA, interval boundaries were jointly defined using the spline curves for both outcomes, with the lower bound constrained by the SGA curve and the upper bound by the LGA curve. These z-score thresholds were subsequently translated back to absolute GWG values at specific gestational ages to facilitate clinical interpretation and visualization.

Additional analyses were performed to explore the cross-sectional associations between dietary nutrient intakes and GWG z-scores. Maternal dietary intake was assessed using a validated semi-quantitative food frequency questionnaire (FFQ) at the time of the mid-to-late pregnancy weight measurement (24-32 gestational weeks). Nutrient intakes were energy-adjusted using the residual method. The associations between each energy-adjusted nutrient intake (per 1-SD increase) and GWG z-score were investigated using linear regression models adjusted for maternal age, pre-pregnancy BMI, parity, FBG, TC, TG, LDL-C, and HDL-C. False discovery rate (FDR)-adjusted q values were calculated using the Benjamini-Hochberg procedure. All statistical analyses were performed using Stata version 18.0 (StataCorp).

RESULTS

Study population characteristics

A total of 1,673 women with GDM were included in the analysis. The mean maternal age was 31.3 (SD 3.7) years, and 15.9% of participants were aged 35 years or older. Most women were nulliparous (66.1%) and had a normal pre-pregnancy BMI 66.7%, while 22.9% were classified as overweight or obese.

When stratified by gestational age-adjusted standardized residuals of gestational weight gain (GWG z-score), women with lower GWG z-scores (<-1) had a higher mean pre-pregnancy BMI and a greater proportion of overweight or obesity compared with those in the reference group (-1 to 1). Mean absolute weight gain during mid-to-late pregnancy increased progressively across z-score categories. Gestational age at delivery was similar across groups, whereas mean infant birth weight was lowest among women with lower GWG z-scores and highest among those with higher GWG z-scores (Table 1).

Associations between GWG z-scores and adverse birth outcomes

In multivariable logistic regression models adjusted for maternal age, pre-pregnancy BMI, parity, FBG, TC, TG, LDL-C and HDL-C, each 1-SD increase in GWG z-score was associated with 45% lower odds of SGA (adjusted OR 0.55, 95% CI 0.43-0.71) (Table 2). Consistent with this finding, when GWG z-scores were categorized, women with lower z-scores (<-1) had higher odds of SGA (adjusted OR 2.36, 95% CI 1.39-4.00), whereas those with higher z-scores (≥1) had lower odds (adjusted OR 0.34, 95% CI 0.13-0.86). For LGA, each 1-SD increase in GWG z-score was associated with 48% higher odds (adjusted OR 1.48, 95% CI 1.29-1.70) (Table 2). Similarly, women with higher GWG z-scores (≥1) had increased odds of LGA (adjusted OR 2.00, 95% CI 1.42-2.82), whereas those with lower z-scores (<-1) had reduced odds (adjusted OR 0.53, 95% CI 0.33-0.84). No clear associations were observed between GWG z-scores and preterm birth, whether modeled as a continuous or categorical variable.

Subgroup and interaction analyses

The associations between GWG z-scores and birth outcomes were generally consistent across predefined subgroups stratified by pre-pregnancy BMI, maternal age, parity, and infant sex (Table 3). Higher GWG z-scores were consistently associated with lower odds of SGA and higher odds of LGA across most subgroups. No statistically significant interactions were

detected between GWG z-scores and any subgroup variables for SGA, LGA, or preterm birth (all *p* for interaction >0.05).

Sensitivity analyses

Results from sensitivity analyses were largely consistent with the primary findings (Supplementary Table 1). Additional adjustment for maternal income and education level did not materially change the associations between GWG z-scores and birth outcomes. Exclusion of women with extreme GWG z-scores (absolute value ≥3), women with gestational hypertension, or infants with complications at birth yielded consistent estimates for SGA, LGA, and preterm birth, supporting the robustness of the main results.

Restricted cubic spline analyses

Using restricted cubic spline models, we further examined the potential non-linear association between GWG z-scores and odds of SGA (Figure 1A) and LGA (Figure 1B). The association was monotonic and approximately linear on the log-odds scale (*p*-nonlinearity: 0.91 for SGA curve and 0.80 for LGA curve; *p*-linearity: 1.25×10^{-4} for SGA curve and 9.76×10^{-7} for LGA curve), with increasing GWG z-scores associated with higher odds of LGA and lower odds of SGA.

By jointly considering the spline curves for SGA and LGA, we identified a GWG z-score of -0.07 as the point at which the odds of both outcomes were closest to unity. Using predefined OR thresholds, the joint interval corresponding to an OR of 1.2 was bounded by z-scores of -0.43 and 0.56, whereas the interval corresponding to an OR of 1.5 extended from -0.84 to 1.17. To enhance clinical interpretability, these z-score cutoffs were translated back to absolute GWG values at specific gestational ages (Figure 1C and Supplementary Table 2). For example, at 28 weeks of gestation, the joint OR = 1.2 interval corresponded to an absolute GWG of approximately 8.17 to 8.30 kg. Similar gestational age-specific patterns were observed across the 24-to-32-week window, illustrating the corresponding absolute GWG values for each predefined z-score interval between gestational 24 and 32 weeks.

Associations between dietary nutrients intake and GWG z-score

We further examined the cross-sectional associations between energy-adjusted nutrient intakes and GWG z-scores in women with GDM. Total energy intake ($\beta = 0.12$, $q = 3.46\times10^{-7}$) and carbohydrate intake ($\beta = 0.10$, $q = 6.86\times10^{-5}$) were positively associated with GWG z-score. In contrast, total protein ($\beta = -0.15$, $q = 1.81\times10^{-9}$), animal protein ($\beta = -0.13$, q =

1.37×10^{-7}), fat (β = -0.06, q = 2.17×10^{-2}), and fiber intake (β = -0.05, q = 2.77×10^{-2}) were inversely associated with GWG z-score, whereas plant protein intake showed no significant association (Table 4). These findings indicate that macronutrient composition, in addition to total energy intake, is associated with mid-to-late pregnancy GWG among women with GDM.

DISCUSSION

In this prospective cohort study of women with GDM, we investigated the associations between gestational age-adjusted standardized residuals of gestational weight gain (GWG z-score) and adverse birth outcomes. We observed that lower GWG z-score was associated with higher odds of SGA, whereas higher GWG z-score was associated with higher odds of LGA. These associations were monotonic and approximately linear on the log-odds scale. By jointly considering the associations with both SGA and LGA, we further identified z-score ranges corresponding to specific odds ratio thresholds and translated these standardized values into gestational age-specific absolute GWG values to enhance clinical interpretability.

Our findings are consistent with previous studies indicating that insufficient GWG is associated with a higher risk of SGA,[10-13] whereas excessive GWG is associated with an increased risk of LGA among women with GDM,[6,10,14] underscoring the clinical challenge of balancing fetal growth restriction and overgrowth in this high-risk population. Accordingly, several studies have attempted to identify GWG ranges associated with the lowest risk of adverse birth outcomes.[7-9] Specifically, For example, a large prospective study including 3,013 women with GDM and 9,115 women without GDM reported that, among normal-weight women with GDM, a total GWG of 9.5-14.0 kg was associated with a lower risk of LGA and a comparable risk of SGA compared with women who met the IOM recommendations.[7] Similarly, other studies have suggested that reducing total GWG by approximately 1-2 kg relative to the IOM targets may confer more favorable birth outcomes in women with GDM.[8,9] While these studies provide important evidence supporting modified total GWG targets for GDM pregnancies, their utility for timely clinical intervention remains limited, as total GWG can only be fully ascertained at delivery.

In contrast to studies focusing on total GWG, a retrospective study of 1,820 pregnant women with GDM examined weekly GWG between the second and third trimesters in relation to adverse birth outcomes and reported that a slightly higher rate of weight gain during this period, compared with the IOM recommendations, was associated with more favorable outcomes.[15] Notably, whereas earlier studies predominantly suggested that women with GDM should adhere to reduced total GWG targets relative to the IOM guidelines, this

study proposed that GWG velocity from mid-to-late pregnancy might not necessarily be lower and may even be modestly higher than that recommended for the general obstetric population. Taken together, these findings suggest that GWG patterns in women with GDM may be more complex than can be captured by total GWG alone and may differ across gestational periods. This further highlights the importance of monitoring and managing GWG dynamically during pregnancy, rather than relying solely on cumulative weight gain assessed at delivery.

Although the Institute of Medicine (IOM) provides recommended rates of GWG during the second and third trimesters for the general obstetric population (e.g. 0.38-0.50 kg/week for normal weight women), and several studies have proposed modified targets specifically for women with GDM, the practical applicability of these recommendations remains limited. Those recommendations are expressed in terms of weight gain velocity that requires repeated measurements and is therefore less intuitive for real-time clinical assessment. The evaluations grounded in the empirical distribution of gestational weight gain and directly linked to specific gestational weeks are still lacking. In the present study, we leveraged the observed distribution of gestational weight gain among women with GDM to derive gestational age-specific GWG z-scores. By jointly examining spline-based associations for SGA and LGA, we identified z-score values at the odds of SGA and LGA were closest to unity, as well as broader intervals corresponding to modestly elevated odds. Translating these z-score thresholds back into absolute GWG values across gestational weeks further provides a practical framework for contextualizing observed weight gain during routine prenatal visits. Notably, the GWG intervals identified in this study were relatively narrow. This finding likely reflects the heightened metabolic vulnerability of pregnancies complicated by GDM,[21,22] in which even modest deviations in weight gain may be associated with measurable increases in the risk of fetal growth restriction or overgrowth.

Previous studies have highlighted the important role of dietary factors in the development of GDM.[23,24] Our study further suggested that energy and carbohydrate intakes were positively, whereas total protein (particularly animal protein), fat and fiber intakes were inversely associated with GWG z-scores. These observations indicate the potential role of balanced nutrient supply in gestational weight gain among GDM women. However, these findings should be interpreted as observational associations rather than causal relationships, as dietary data were collected cross-sectionally via FFQ at the time of weight measurement. Notably, our results do not support overly restrictive carbohydrate intake in women with GDM. Instead, carbohydrate intake should remain within recommended ranges (e.g., a

minimum of 175 g/day), with emphasis on high-quality sources characterized by low glycemic index and high fiber content.[25]

Key strengths of this study include the prospective design, the focus on a well-characterized cohort of women with GDM, and the use of gestational age-adjusted standardized residuals to capture deviations in GWG. Several limitations should be acknowledged. First, as an observational study, residual confounding cannot be excluded, despite adjustment for major maternal characteristics and sensitivity analyses. Second, gestational weight gain was calculated as the difference between measured body weight at 24-32 weeks of gestation and self-reported pre-pregnancy weight. Self-reported pre-pregnancy weight is subject to recall bias, and women commonly tend to under-report their pre-pregnancy weight, which may result in overestimation of actual GWG. Third, we acknowledge the potential for reverse causality, whereby larger fetuses may contribute to higher measured maternal weight gain. This bidirectional relationship is a well-recognized challenge in observational GWG research. However, our study focused on describing associations between gestational age-adjusted GWG and birth outcomes rather than inferring any causality. Fourth, the study population was drawn from a single cohort in China, which may limit generalizability to other populations with different demographic or clinical profiles. Finally, our analyses focused on the 24-32-week window and do not investigate maternal weight gain earlier or later in pregnancy.

Conclusion

In conclusion, this study demonstrates that gestational age-adjusted GWG during mid-to-late pregnancy is associated with both SGA and LGA among women with GDM, with opposing directions of association. By jointly characterizing these associations and translating standardized deviations into absolute gestational age-specific GWG values, our findings provide a nuanced and clinically interpretable framework for understanding weight gain during a critical period of pregnancy. Further large-scale studies are needed to refine these gestational age-specific GWG intervals.

SUPPLEMENTARY MATERIALS

All supplementary tables and figures are available upon request from the editorial office, and are also accessible on the journal's webpage (apjcn.qdu.edu.cn).

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CONFLICT OF INTEREST AND FUNDING DISCLOSURE

The authors declare no competing interests.

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Table 1. Maternal and neonatal characteristics of women with gestational diabetes mellitus

Characteristics		GWG z-score			
	Total (n = 1673)	< -1 (n = 232)	-1 to 1 (n = 1186)	≥ 1 (n = 255)	p
Maternal age (year), mean (SD)	31.3 (3.7)	31.5 (3.5)	31.2 (3.7)	31.3 (4.2)	0.66
Maternal age ≥ 35 years, n (%)	266 (15.9)	42 (18.1)	175 (14.8)	49 (19.2)	0.13
Nulliparous, n (%)	1105 (66.1)	131 (56.5)	802 (67.6)	172 (67.5)	0.02
Pre-pregnancy BMI (kg/m^2), mean (SD)	21.9 (3.1)	23.5 (4.0)	21.7 (2.9)	21.6 (2.6)	< 0.001
Pre-pregnancy BMI categories, n (%)					
Underweight (<18.5 kg/m^2)	175 (10.5)	11 (4.7)	137 (11.6)	27 (10.6)	< 0.001
Normal weight (18.5-23.9 kg/m^2)	1115 (66.7)	125 (53.9)	808 (68.1)	182 (82.0)	
Overweight and obese (≥ 24 kg/m2)	383 (22.9)	96 (41.4)	241 (20.3)	46 (18.0)	
GWG (kg), mean (SD)	7.3 (3.4)	2.5 (1.7)	7.1 (1.9)	12.7 (2.1)	0.005
GA at delivery (week), median (IQR range)	39 (38-39)	39 (38-39)	39 (38-40)	39 (38-39)	0.08
Infant birth weight (g), mean (SD)	3259 (468)	3152 (439)	3255 (455)	3376 (528)	0.003
Male infant, n (%)	878 (52.5%)	110 (47.4)	633 (53.4)	135 (52.9)	0.25

BMI, body mass index; GWG: gestational weight gain; IQR: interquartile ranges; SD: standard deviation.
Group differences were assessed using analysis of variance (ANOVA) for normally distributed continuous variables and the Kruskal-Wallis test for non-normally distributed continuous variables, chi-square tests were used for categorical variables.

Table 2. Associations of GWG z-scores with adverse birth outcomes among women with gestational diabetes mellitus

Outcomes and GWG z-scores	Cases/total	OR (95% CI)	
		Crude model	Adjusted model
SGA			
< -1	22/210	1.72 (1.04, 2.85)	2.36 (1.39, 4.00)
-1 to 1	68/1118	1 (Ref)	1 (Ref)
≥ 1	5/250	0.33 (0.13, 0.82)	0.34 (0.13, 0.86)
Per 1 SD increase	95/1578	0.65 (0.52, 0.81)	0.55 (0.43, 0.71)
LGA			
< -1	27/205	0.79 (0.51, 1.21)	0.53 (0.33, 0.84)
-1 to 1	170/1016	1 (Ref)	1 (Ref)
≥ 1	65/190	2.04 (1.48, 2.83)	2.00 (1.42, 2.82)
Per 1 SD increase	262/1411	1.36 (1.20, 11.55)	1.48 (1.29, 1.70)
Preterm birth			
< -1	15/217	1.15 (0.65, 2.06)	1.12 (0.62, 2.05)
-1 to 1	67/1119	1 (Ref)	1 (Ref)
≥ 1	15/240	1.04 (0.59, 1.86)	1.06 (0.59, 1.91)
Per 1 SD increase	97/1576	1.00 (0.81, 1.22)	1.02 (0.82, 1.26)

BMI, body mass index; FBG, fasting blood glucose; TC, total cholesterol; TG, triglycerides; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; GWG, gestational weight gain; SGA, small for gestational age; LGA, large for gestational age; OR, odds ratio; CI, confidence interval; SD, standard deviation.
Logistic regression models were used to investigate the associations of z-score categories (with -1 to 1 as the reference group) and per 1-SD increase in z-score with the odds of SGA, LGA, and preterm birth among women with gestational diabetes mellitus. The GWG z-score represents gestational-age-adjusted standardized residuals of weight gain at mid-to-late gestation. Crude models and models adjusted for maternal age, pre-pregnancy BMI, parity, FBG, TC, TG, LDL-C, and HDL-C were fitted.

Table 3. Subgroup analyses of the associations between per 1-SD increase GWG z-score and adverse birth outcomes among women with gestational diabetes mellitus

Subgroup	SGA			LGA			Preterm birth		
	Cases/total	OR (95% CI)	p-interaction	Cases/total	OR (95% CI)	p-interaction	Cases/total	OR (95% CI)	p-interaction
Pre-pregnancy BMI									
<18.5	16/175	0.46 (0.21, 1.04)	0.61	15/175	2.71 (1.36, 5.39)	0.12	12/175	1.13 (0.52, 2.45)	0.62
18.5-23.9	70/1115	0.57 (0.43, 0.75)		146/1115	1.31 (1.09, 1.57)		60/1115	1.15 (0.87, 1.52)	
≥24	9/383	0.78 (0.41, 1.50)		101/383	1.65 (1.31, 2.08)		25/383	0.86 (0.57, 1.30)	
Maternal age									
< 35	85/1407	0.55 (0.42, 0.72)	0.88	201/1407	1.48 (1.27, 1.73)	0.91	80/1407	1.01 (0.80, 1.28)	0.91
≥35	10/266	0.55 (0.25, 1.24)		61/266	1.48 (1.09, 2.01)		17/286	1.05 (0.63, 1.74)	
Parity									
Nulliparous	82/1105	0.56 (0.42, 0.74)	0.94	138/1105	1.43 (1.19, 1.72)	0.69	67/1105	0.98 (0.75, 1.27)	0.61
Multiparous	13/568	0.55 (0.30, 1.01)		124/568	1.55 (1.25, 1.91)		30/568	1.10 (0.75, 1.61)	
Infant sex									
Male	49/878	0.48 (0.34, 0.68)	0.32	138/878	1.48 (1.22, 1.79)	0.88	62/878	1.00 (0.76, 1.31)	0.89
Female	46/795	0.65 (0.45, 0.93)		124/795	1.51 (1.24, 1.85)		35/795	1.07 (0.76, 1.52)	

BMI, body mass index; FBG, fasting blood glucose; TC, total cholesterol; TG, triglycerides; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; GWG, gestational weight gain; SGA, small for gestational age; LGA, large for gestational age; OR, odds ratio; CI, confidence interval.
ORs and 95% CIs were estimated using logistic regression models adjusted for maternal age, pre-pregnancy BMI, parity, FBG, TC, TG, LDL-C, and HDL-C. p values for interaction were obtained by including an interaction term between the z-score and stratification factors in the models.

Table 4. Associations between dietary nutrient intakes and GWG z-score among women with gestational diabetes mellitus

Exposures	β †	p	q
Energy intake	0.12	1.48×10^{-7}	3.46×10^{-7}
Carbohydrate‡	0.10	3.92×10^{-5}	6.86×10^{-5}
Fat‡	-0.06	1.55×10^{-2}	2.17×10^{-2}
Total protein‡	-0.15	2.58×10^{-10}	1.81×10^{-9}
Animal protein‡	-0.13	3.92×10^{-8}	1.37×10^{-7}
Plant protein‡	0.01	5.59×10^{-1}	5.59×10^{-1}
Fiber‡	-0.05	2.38×10^{-2}	2.77×10^{-2}

BMI, body mass index; FBG, fasting blood glucose; TC, total cholesterol; TG, triglycerides; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol..

†Represents the change in GWG z-score per 1 standard deviation increase in dietary exposure, estimated using linear regression models adjusted for maternal age, pre-pregnancy BMI, parity, FBG, TC, TG, LDL-C, and HDL-C.

‡All the dietary exposures were energy-adjusted. q values were calculated using the Benjamini–Hochberg method to control for false discovery rate

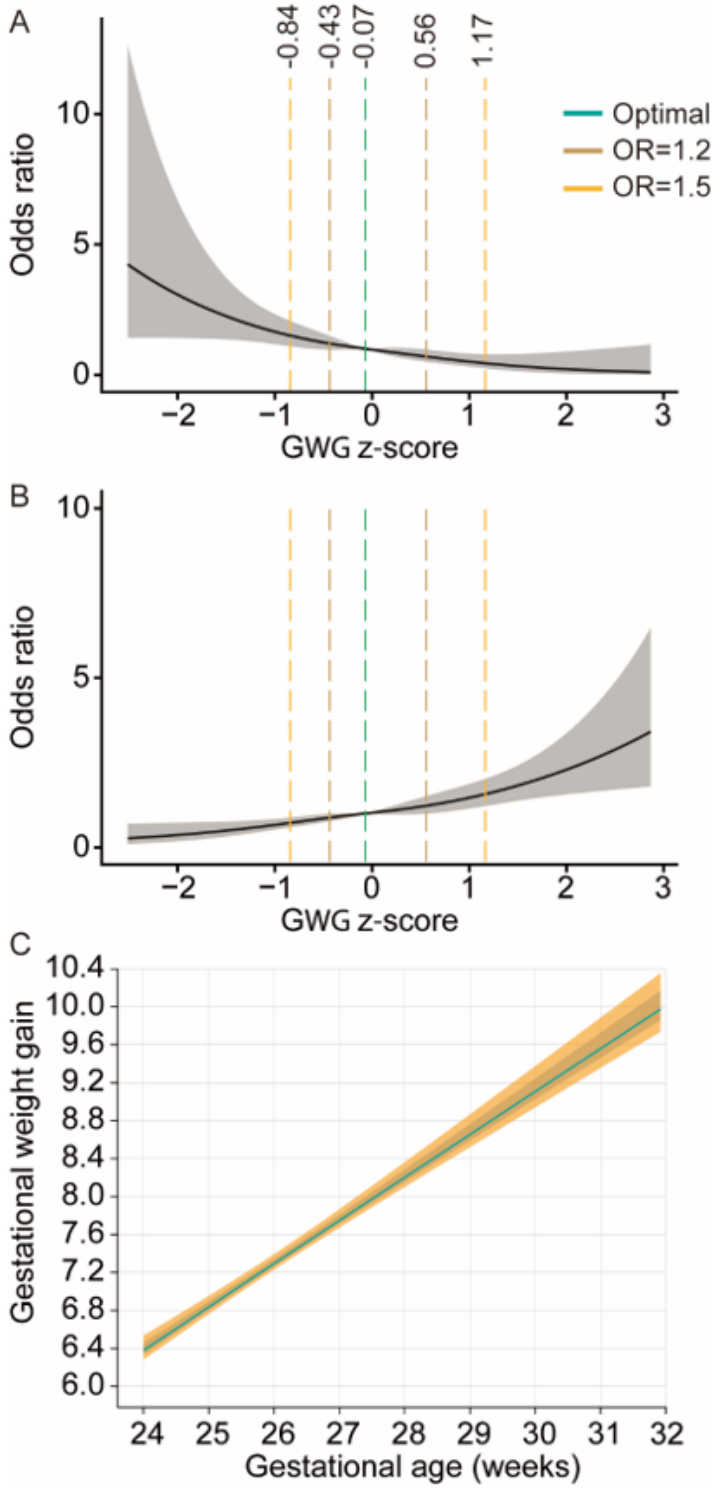

Figure 1. Non-linear associations between GWG z-score and odds of SGA and LGA among women with gestational diabetes mellitus. Restricted cubic spline models depict the associations between GWG z-scores and odds of SGA (A) and LGA (B), with the reference set at z-score = 0. Panel (C) shows the translation of selected z-score thresholds corresponding to ORs of 1.0 (green line), 1.2 (brown), and 1.5 (yellow) into absolute GWG values across gestational ages, based on joint consideration of the SGA and LGA spline curves. The -nonlinearity was 0.91 for SGA curve and 0.80 for LGA curve, and the p-linearity was 1.25×10-4 for SGA curve and 9.76×10-7 for LGA curve. GWG, gestational weight gain; SGA, small for gestational age; LGA, large for gestational age; OR, odds ratio.