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Interactions of pre-pregnancy body mass index with early- and mid-pregnancy gestational weight gain in relation to gestational diabetes mellitus: a retrospective cohort study

Huixia Peng[1]
Hunan University of Traditional Chinese Medicine
Hui Yang[2]
Second Xiangya Hospital of Central South University
Wen Zhao[2]
Second Xiangya Hospital of Central South University
Lulu Qin[1]
Hunan University of Traditional Chinese Medicine
Junru Yi[3]
Zhuzhou Central Hospital
Rongchen Jin[1]
342806448@qq.com

Hunan University of Traditional Chinese Medicine

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Abstract

Background

Pre-pregnancy body mass index (BMI) and gestational weight gain (GWG) are important weight-related factors associated with gestational diabetes mellitus (GDM). Their stage-specific interactions remain uncertain. We examined the independent associations of these factors with GDM. We also examined their interactions and joint associations.

Methods

This retrospective cohort study included 1,661 pregnant women. All participants received regular antenatal care and completed GDM screening at a tertiary hospital in Changsha, China. Univariable and multivariable logistic regression models were used to assess independent associations. Pairwise product terms were used to assess multiplicative interactions. Modified Poisson regression was used to assess additive interactions. A three-factor joint analysis combined pre-pregnancy BMI with early- and mid-pregnancy GWG categories.

Results

GDM was diagnosed in 372 women (22.4%). Pre-pregnancy overweight/obesity was associated with a higher GDM risk than normal BMI (aOR 2.213, 95% CI 1.655–2.958). Pre-pregnancy underweight was associated with a lower risk (aOR 0.547, 95% CI 0.337–0.887). Early- and mid-pregnancy GWG categories were not independently associated with GDM. Pre-pregnancy BMI interacted significantly with early-pregnancy GWG on the multiplicative scale ($P < 0.001$). Overweight/obesity and insufficient early-pregnancy GWG showed a negative additive interaction. The RERI was − 1.011 (95% CI − 1.773 to − 0.249). The AP was − 0.808 (95% CI − 1.597 to − 0.019). No significant multiplicative interaction was found for pre-pregnancy BMI with mid-pregnancy GWG ($P = 0.939$). No significant multiplicative interaction was found between early- and mid-pregnancy GWG ($P = 0.190$). Six joint categories showed significantly elevated GDM risk. All six occurred among women with pre-pregnancy overweight/obesity. Among women with excessive early-pregnancy GWG, elevated risk was seen across all mid-pregnancy GWG categories.

Conclusions

Pre-pregnancy overweight/obesity was associated with higher GDM risk. The strength of this association differed across early-pregnancy GWG categories. These findings support preconception weight management. They also support BMI-informed monitoring of weight change during early pregnancy.

Background

Gestational diabetes mellitus (GDM) is a glucose metabolism disorder first recognized during pregnancy. It is one of the most common metabolic complications of pregnancy [1]. The global prevalence of GDM is approximately 14.0% [2]. GDM is associated with adverse pregnancy outcomes [3, 4]. It is also associated with a higher long-term risk of type 2 diabetes and other metabolic disorders in mothers and offspring [5, 6]. Early identification and management of modifiable GDM risk factors are therefore clinically important.

Pre-pregnancy overweight and obesity are well-established risk factors for GDM [7, 8]. However, unintended pregnancies remain common [9]. Many women also enter pregnancy without achieving an optimal pre-pregnancy weight [10]. Appropriate gestational weight gain (GWG) is therefore an important component of antenatal weight management [11]. Current practice commonly uses BMI-specific GWG recommendations. These include guidance from the Institute of Medicine/National Academy of Medicine. China has also issued the Weight Gain Recommendation for Women During Pregnancy (WS/T 801–2022) [12]. The association between GWG at different gestational stages and GDM remains controversial [13–15]. Most previous studies focused on cumulative weight gain before GDM diagnosis [13, 16]. The independent roles of early- and mid-pregnancy GWG have received less attention. Some studies linked rapid early-pregnancy weight gain to higher GDM risk [13, 14]. Other studies emphasized mid-pregnancy weight gain [17]. Several studies found no significant association [18, 19].

These inconsistent findings may partly reflect differences in pre-pregnancy BMI. Baseline metabolic status and GWG patterns vary across BMI groups [14, 16, 20]. Important questions therefore remain. Women with overweight/obesity may retain high GDM risk even when GWG is within recommended ranges. Women with normal BMI may also tolerate different GWG patterns differently. Few studies have evaluated early- and mid-pregnancy GWG together in relation to GDM. Few have also examined early- and mid-pregnancy GWG combinations across pre-pregnancy BMI strata. We first evaluated the independent associations of pre-pregnancy BMI and stage-specific GWG with GDM. We then assessed pairwise multiplicative and additive interactions. Finally, we performed a three-factor joint analysis to identify high-risk GWG combinations within pre-pregnancy BMI strata.

Methods

Study design and participants

The study aimed to assess the independent, interactive, and joint associations of pre-pregnancy BMI and stage-specific GWG with GDM. This retrospective cohort study was conducted at a tertiary hospital in Changsha, Hunan Province, China. The study period was January 2025 to February 2026. The study population consisted of pregnant women receiving regular antenatal care and completing GDM screening. Inclusion required complete data on age and pre-pregnancy BMI. Complete weight records were also required for early pregnancy and mid-pregnancy. Participants also had to complete a 75-g oral

glucose tolerance test (OGTT) at 24–28 weeks of gestation. We excluded women with diabetes diagnosed before pregnancy. We also excluded multiple pregnancies and severe major-organ disease. The final analysis included 1,661 women (Fig. 1).

The study was approved by the Science and Technology Ethics Review Committee for Nursing and Behavioral Medicine, Hunan University of Chinese Medicine (approval no. ZYYHLL-2026-04-005). The study followed the Declaration of Helsinki. The requirement for informed consent was waived by the ethics committee.

Data collection

Data were extracted from the hospital electronic medical record system and the obstetric outpatient follow-up database. We collected maternal age, height, pre-pregnancy weight, mode of conception, and parity. We also collected polycystic ovary syndrome (PCOS), history of GDM, and family history of diabetes. Pregnancy weight records and 75-g OGTT results were also obtained.

Pre-pregnancy BMI was calculated from self-reported pre-pregnancy weight and measured height. The pre-pregnancy weight was recorded at the first antenatal visit. Gestational weights were measured during antenatal visits. Early-pregnancy endpoint weight was the last measured weight from 0 to 12 + 6 weeks. Mid-pregnancy GWG used this weight as the starting weight. The endpoint was the last measured weight from 24 + 0 to 24 + 6 weeks. If several measurements were recorded on the same gestational day, the first measurement was used.

Definitions and exposure classification

GDM was diagnosed according to the American Diabetes Association Standards of Care in Diabetes—2024 [21]. Pregnant women underwent a 75-g OGTT at 24–28 weeks of gestation. GDM was diagnosed if any threshold was met or exceeded. The thresholds were fasting plasma glucose 5.1 mmol/L, 1-h plasma glucose 10.0 mmol/L, and 2-h plasma glucose 8.5 mmol/L.

Chinese adult BMI criteria were used [22]. For regression analyses, pre-pregnancy BMI was classified as underweight (< 18.5 kg/m²), normal weight (18.5 to < 24.0 kg/m²), or overweight/obesity (≥ 24.0 kg/m²). Mid-pregnancy GWG adequacy was determined using BMI-specific recommendations. These recommendations distinguish underweight, normal weight, overweight (24.0 to < 28.0 kg/m²), and obesity (≥ 28.0 kg/m²). The recommended weekly gain differs between overweight and obesity.

The Chinese Weight Gain Recommendation for Women During Pregnancy (WS/T 801–2022) was used [12]. The recommended total gain in early pregnancy, up to 12 + 6 weeks, is 0–2.0 kg for all BMI groups. BMI-specific weekly ranges were used for mid-pregnancy, from 13 + 0 to 24 + 6 weeks. The ranges are 0.37–0.56 kg/week for underweight and 0.26–0.48 kg/week for normal weight. They are 0.22–0.37 kg/week for overweight and 0.15–0.30 kg/week for obesity. Gain below the relevant range was classified

as insufficient. Gain within the range was classified as appropriate. Gain above the range was classified as excessive.

Early-pregnancy GWG was calculated from pre-pregnancy weight and the last measured weight at 12 + 0 to 12 + 6 weeks. Mid-pregnancy average weekly GWG used the early-pregnancy endpoint weight as the starting value. The measured weight at 24 + 0 to 24 + 6 weeks was the endpoint. The weight difference was divided by 12 weeks.

Statistical analysis

Statistical analyses were performed using R version 4.4.1. Maternal age is presented as mean ± standard deviation. Categorical variables are presented as numbers and percentages [n (%)]. GDM status was the dependent variable. Univariable logistic regression was used for each candidate factor. The factors were age, mode of conception, parity, PCOS, history of GDM, and family history of diabetes. Pre-pregnancy BMI and early- and mid-pregnancy GWG were also included. All factors were then entered into multivariable logistic regression models. Univariable results are reported as odds ratios (ORs) with 95% confidence intervals (CIs). Multivariable results are reported as adjusted odds ratios (aORs) with 95% CIs. Variable coding is shown in Table 2. Pairwise product terms were added to assess multiplicative interactions. Modified Poisson regression was used to assess additive interactions. We calculated the relative excess risk due to interaction (RERI), attributable proportion due to interaction (AP), and synergy index (SI), with 95% CIs. A three-factor joint variable was also created. It combined the categories of pre-pregnancy BMI, early-pregnancy GWG, and mid-pregnancy GWG. The reference group had normal pre-pregnancy BMI, appropriate early-pregnancy GWG, and appropriate mid-pregnancy GWG. Statistical significance was defined as $P < 0.05$. The study included all eligible women during the predefined study period. No a priori sample size calculation was performed.

Table 2
Variable coding for logistic regression analyses

Variable	Variable type	Coding
GDM	Binary outcome	Non-GDM = 0; GDM = 1
Age	Continuous	Actual age (years)
Mode of conception	Binary	Spontaneous = 0; assisted reproduction = 1
Parity	Binary	Nulliparous = 0; multiparous = 1
Polycystic ovary syndrome	Binary	No = 0; yes = 1
History of GDM	Binary	No = 0; yes = 1
Family history of diabetes	Binary	No = 0; yes = 1
Pre-pregnancy BMI	Three-category	Normal (Ref.): 00; underweight: 10; overweight/obesity: 01
Early-pregnancy GWG	Three-category	Appropriate (Ref.): 00; insufficient: 10; excessive: 01
Mid-pregnancy GWG	Three-category	Appropriate (Ref.): 00; insufficient: 10; excessive: 01

Note: Pre-pregnancy BMI and early- and mid-pregnancy GWG were entered as dummy variables in the order X1, X2. Ref., reference category.

Study reporting

This report follows the STROBE statement for cohort studies.

Use of AI-assisted language tools

ChatGPT (OpenAI) was used for English translation, language editing, and manuscript formatting. The authors reviewed and revised all AI-assisted text. The tool was not used to generate or alter the study data or statistical results. The authors take full responsibility for the manuscript.

Results

Participant characteristics

The final cohort included 1,661 women. GDM was diagnosed in 372 women, giving a prevalence of 22.4%. Table 1 shows age, mode of conception, parity, PCOS, history of GDM, and family history of diabetes. It also shows pre-pregnancy BMI and early- and mid-pregnancy GWG categories.

Table 1
Baseline characteristics of the study population

Variable	All participants (n = 1661)
Age, years	31.51 ± 4.14
GDM diagnosis, n (%)	
Non-GDM	1289 (77.6)
GDM	372 (22.4)
Mode of conception, n (%)	
Spontaneous conception	1392 (83.8)
Assisted reproduction	269 (16.2)
Parity, n (%)	
Nulliparous	1029 (62.0)
Multiparous	632 (38.0)
Polycystic ovary syndrome, n (%)	
No	1389 (83.6)
Yes	272 (16.4)
History of GDM, n (%)	
No	1623 (97.7)
Yes	38 (2.3)
Family history of diabetes, n (%)	
No	1282 (77.2)
Yes	379 (22.8)
Pre-pregnancy BMI category, n (%)	
Normal weight	1170 (70.4)
Underweight	183 (11.0)
Overweight/obesity	308 (18.5)
Early-pregnancy GWG category, n (%)	
Appropriate	675 (40.6)
Insufficient	444 (26.7)
Excessive	542 (32.6)

Variable	All participants (n = 1661)
Mid-pregnancy GWG category, n (%)	
Appropriate	605 (36.4)
Insufficient	253 (15.2)
Excessive	803 (48.3)

Logistic regression analyses of GDM risk factors

Variable coding for logistic regression is shown in Table 2. Univariable and multivariable results are shown in Table 3. The multivariable model adjusted for age, mode of conception, parity, PCOS, history of GDM, and family history of diabetes. It also adjusted for early- and mid-pregnancy GWG. Pre-pregnancy underweight was associated with lower GDM risk than normal BMI (aOR 0.547, 95% CI 0.337–0.887, P = 0.014). Pre-pregnancy overweight/obesity was associated with higher GDM risk (aOR 2.213, 95% CI 1.655–2.958, P < 0.001). Neither early- nor mid-pregnancy GWG category was significantly associated with GDM (both P > 0.05).

Table 3
Univariable and multivariable logistic regression analyses of GDM risk factors

Variable	Univariable				Multivariable			
	B	SE	OR (95% CI)	P	B	SE	aOR (95% CI)	P
Age, years	0.079	0.014	1.082 (1.053–1.113)	< 0.001*	0.058	0.016	1.060 (1.028–1.093)	< 0.001*
Mode of conception								
Spontaneous			1.00 (Ref.)	—			1.00 (Ref.)	—
Assisted reproduction	0.354	0.151	1.425 (1.060–1.916)	0.019*	0.414	0.167	1.513 (1.091–2.098)	0.013*
Parity								
Nulliparous			1.00 (Ref.)	—			1.00 (Ref.)	—
Multiparous	0.296	0.120	1.344 (1.064–1.699)	0.013*	0.328	0.137	1.388 (1.061–1.815)	0.017*
Polycystic ovary syndrome								
No			1.00 (Ref.)	—			1.00 (Ref.)	—
Yes	0.268	0.152	1.307 (0.970–1.761)	0.079	0.067	0.163	1.069 (0.777–1.472)	0.682
History of GDM								
No			1.00 (Ref.)	—			1.00 (Ref.)	—
Yes	1.171	0.330	3.226 (1.688–6.165)	< 0.001*	1.024	0.355	2.783 (1.387–5.586)	0.004*
Family history of diabetes								

Note: *P < 0.05. OR, odds ratio; aOR, adjusted odds ratio; CI, confidence interval; Ref., reference category.

Variable	Univariable				Multivariable			
	B	SE	OR (95% CI)	P	B	SE	aOR (95% CI)	P
No			1.00 (Ref.)	—			1.00 (Ref.)	—
Yes	0.958	0.129	2.607 (2.025–3.357)	< 0.001*	0.862	0.134	2.367 (1.821–3.077)	< 0.001*
Pre-pregnancy BMI								
Normal			1.00 (Ref.)	—			1.00 (Ref.)	—
Underweight	−0.559	0.235	0.572 (0.361–0.906)	0.017*	−0.603	0.247	0.547 (0.337–0.887)	0.014*
Overweight/obesity	0.849	0.139	2.338 (1.781–3.069)	< 0.001*	0.794	0.148	2.213 (1.655–2.958)	< 0.001*
Early-pregnancy GWG								
Appropriate			1.00 (Ref.)	—			1.00 (Ref.)	—
Insufficient	−0.067	0.149	0.935 (0.698–1.253)	0.654	−0.030	0.156	0.970 (0.714–1.318)	0.847
Excessive	0.108	0.137	1.114 (0.852–1.457)	0.431	0.070	0.145	1.072 (0.808–1.424)	0.630
Mid-pregnancy GWG								
Appropriate			1.00 (Ref.)	—			1.00 (Ref.)	—
Insufficient	0.161	0.176	1.175 (0.831–1.660)	0.362	0.143	0.187	1.154 (0.800–1.665)	0.444
Excessive	0.037	0.130	1.038 (0.804–1.339)	0.775	−0.052	0.139	0.949 (0.723–1.247)	0.709

Note: *P < 0.05. OR, odds ratio; aOR, adjusted odds ratio; CI, confidence interval; Ref., reference category.

Interaction analyses

Pre-pregnancy BMI interacted significantly with early-pregnancy GWG on the multiplicative scale (P < 0.001). The association of pre-pregnancy overweight/obesity with GDM differed across early-pregnancy GWG categories. The association was significant in the appropriate and excessive GWG groups. It was not significant in the insufficient GWG group. No significant multiplicative interaction was found between pre-pregnancy BMI and mid-pregnancy GWG (P = 0.939). No significant multiplicative interaction was found between early- and mid-pregnancy GWG (P = 0.190) (Table 4). Additive interaction analysis showed a negative interaction between pre-pregnancy overweight/obesity and insufficient early-pregnancy GWG. The RERI was − 1.011 (95% CI − 1.773 to − 0.249). The AP was − 0.808 (95% CI − 1.597 to − 0.019). No other combination showed clear additive interaction (Table 5).

Table 4
Multiplicative interactions between pre-pregnancy BMI and gestational weight gain

Stratum	Category 1 aOR (95% CI)	Category 2 aOR (95% CI)	Category 3 aOR (95% CI)	P for interaction
Pre-pregnancy BMI × early-pregnancy GWG	**Early insufficient**	**Early appropriate**	**Early excessive**	
Underweight	1.608 (0.750–3.447)	0.410 (0.179–0.942)	0.487 (0.215–1.100)	< 0.001
Normal	1.00 (Ref.)	1.00 (Ref.)	1.00 (Ref.)	
Overweight/obesity	0.899 (0.486–1.664)	3.658 (2.368–5.652)	2.209 (1.337–3.651)	
Pre-pregnancy BMI × mid-pregnancy GWG	**Mid insufficient**	**Mid appropriate**	**Mid excessive**	
Underweight	0.535 (0.217–1.321)	0.526 (0.259–1.068)	0.929 (0.397–2.175)	0.939
Normal	1.00 (Ref.)	1.00 (Ref.)	1.00 (Ref.)	
Overweight/obesity	2.065 (0.989–4.315)	2.307 (1.328–4.009)	2.258 (1.547–3.295)	
Early-pregnancy GWG × mid-pregnancy GWG	**Mid insufficient**	**Mid appropriate**	**Mid excessive**	
Early insufficient	1.025 (0.446–2.355)	1.589 (0.964–2.617)	0.785 (0.518–1.192)	0.190
Early appropriate	1.00 (Ref.)	1.00 (Ref.)	1.00 (Ref.)	
Early excessive	0.887 (0.457–1.721)	1.597 (1.002–2.546)	0.895 (0.597–1.341)	

Note: aOR, adjusted odds ratio; CI, confidence interval; Ref., reference category.

Table 5
Additive interactions between pre-pregnancy BMI and gestational weight gain

Factor 1	Factor 2	RERI (95% CI)	AP (95% CI)	SI (95% CI)
Pre-pregnancy BMI	**Early-pregnancy GWG**			
Normal	Appropriate	Reference		
Underweight	Insufficient	0.662 (− 0.251 to 1.574)	0.525 (0.052 to 0.998)	NE
	Excessive	0.009 (− 0.565 to 0.582)	0.014 (− 0.907 to 0.935)	0.978 (0.222–4.309)
Overweight/obesity	Insufficient	−1.011 (− 1.773 to − 0.249)	−0.808 (− 1.597 to − 0.019)	0.199 (0.028–1.419)
	Excessive	−0.406 (− 1.083 to 0.271)	−0.217 (− 0.603 to 0.169)	0.681 (0.365–1.271)
Pre-pregnancy BMI	**Mid-pregnancy GWG**			
Normal	Appropriate	Reference		
Underweight	Insufficient	0.216 (− 0.402 to 0.834)	0.300 (− 0.469 to 1.069)	0.563 (0.100–3.167)
	Excessive	0.533 (− 0.123 to 1.189)	0.620 (0.110 to 1.130)	0.209 (0.004–11.800)
Overweight/obesity	Insufficient	0.081 (− 0.738 to 0.900)	0.046 (− 0.408 to 0.500)	1.118 (0.358–3.489)
	Excessive	0.099 (− 0.447 to 0.644)	0.062 (− 0.276 to 0.399)	1.195 (0.412–3.466)
Early-pregnancy GWG	**Mid-pregnancy GWG**			
Appropriate	Appropriate	Reference		
Insufficient	Insufficient	−0.420 (− 1.430 to 0.590)	−0.313 (− 1.172 to 0.547)	0.450 (0.047–4.318)

Note: Models were adjusted for age, mode of conception, parity, PCOS, history of GDM, family history of diabetes, and the remaining weight-related factor(s) as appropriate. RERI, relative excess risk due to interaction; AP, attributable proportion due to interaction; SI, synergy index; NE, not estimable.

Factor 1	Factor 2	RERI (95% CI)	AP (95% CI)	SI (95% CI)
Pre-pregnancy BMI	**Early-pregnancy GWG**			
	Excessive	−0.666 (− 1.343 to 0.011)	−0.644 (− 1.296 to 0.009)	0.050 (0.000–1500.667)
Excessive	Insufficient	−0.330 (− 1.118 to 0.458)	−0.236 (− 0.822 to 0.351)	0.548 (0.142–2.120)
	Excessive	−0.510 (− 1.118 to 0.099)	−0.441 (− 0.957 to 0.076)	0.235 (0.032–1.755)

Note: Models were adjusted for age, mode of conception, parity, PCOS, history of GDM, family history of diabetes, and the remaining weight-related factor(s) as appropriate. RERI, relative excess risk due to interaction; AP, attributable proportion due to interaction; SI, synergy index; NE, not estimable.

Joint associations of pre-pregnancy BMI and gestational weight gain

The reference group had normal pre-pregnancy BMI, appropriate early-pregnancy GWG, and appropriate mid-pregnancy GWG. Six joint categories showed significantly elevated GDM risk. All six occurred among women with pre-pregnancy overweight/obesity. Women with overweight/obesity and excessive early-pregnancy GWG had higher GDM risk across all mid-pregnancy GWG categories. This pattern was present with appropriate, insufficient, and excessive mid-pregnancy GWG. No joint category in women with normal BMI or underweight was significantly associated with GDM (Table 6).

Table 6
Joint associations of pre-pregnancy BMI, gestational weight gain, and GDM

Pre-pregnancy BMI	Early-pregnancy GWG	Mid-pregnancy GWG	aOR (95% CI)	P
Normal	Appropriate	Appropriate	1.00 (Ref.)	—
		Insufficient	1.091 (0.517–2.303)	0.820
		Excessive	1.062 (0.625–1.805)	0.824
	Insufficient	Appropriate	1.387 (0.762–2.526)	0.284
		Insufficient	1.753 (0.693–4.436)	0.236
		Excessive	1.007 (0.570–1.777)	0.982
	Excessive	Appropriate	1.303 (0.751–2.261)	0.347
		Insufficient	1.453 (0.683–3.092)	0.332
		Excessive	1.098 (0.623–1.936)	0.747
Underweight	Appropriate	Appropriate	0.237 (0.052–1.072)	0.062
		Insufficient	0.795 (0.210–3.012)	0.735
		Excessive	0.452 (0.100–2.043)	0.302
	Insufficient	Appropriate	0.678 (0.184–2.494)	0.559
		Insufficient	3.479 (0.539–22.453)	0.190
		Excessive	3.633 (0.870–15.175)	0.077
	Excessive	Appropriate	0.528 (0.115–2.422)	0.411
		Insufficient	0.537 (0.170–1.699)	0.290

Note: aOR, adjusted odds ratio; CI, confidence interval; Ref., reference category.

Pre-pregnancy BMI	Early-pregnancy GWG	Mid-pregnancy GWG	aOR (95% CI)	P
		Excessive	1.088 (0.189–6.270)	0.924
Overweight/obesity	Appropriate	Appropriate	1.618 (0.669–3.916)	0.286
		Insufficient	4.176 (1.566–11.134)	0.004
		Excessive	4.283 (2.301–7.973)	< 0.001
	Insufficient	Appropriate	2.865 (1.008–8.147)	0.048
		Insufficient	0.472 (0.057–3.926)	0.487
		Excessive	1.191 (0.540–2.626)	0.665
	Excessive	Appropriate	4.479 (1.573–12.754)	0.005
		Insufficient	3.895 (1.321–11.480)	0.014
		Excessive	2.085 (1.026–4.236)	0.042

Note: aOR, adjusted odds ratio; CI, confidence interval; Ref., reference category.

Discussion

This study examined the independent associations of pre-pregnancy BMI and stage-specific GWG with GDM. It also examined their interactions and joint associations. Pre-pregnancy BMI was independently associated with GDM. Overweight/obesity was associated with higher risk, while underweight was associated with lower risk. Early- and mid-pregnancy GWG categories were not independently associated with GDM. Pre-pregnancy BMI interacted significantly with early-pregnancy GWG on the multiplicative scale. Pre-pregnancy overweight/obesity and insufficient early-pregnancy GWG also showed a negative additive interaction. No significant interaction was found for pre-pregnancy BMI with mid-pregnancy GWG. No significant interaction was found between early- and mid-pregnancy GWG. Six joint categories showed significantly elevated GDM risk. All six occurred among women with pre-pregnancy overweight/obesity. The pattern was most consistent in women with excessive early-pregnancy GWG. These findings support pre-pregnancy BMI as a basis for risk stratification. They also suggest an important role for early-pregnancy weight change in risk assessment.

Pre-pregnancy BMI and GDM risk

Pre-pregnancy overweight/obesity was associated with higher GDM risk in our study. Pre-pregnancy underweight was associated with lower risk. These findings are consistent with previous systematic reviews, meta-analyses, and Chinese cohort studies [7, 8, 23]. Pre-pregnancy overweight and obesity may indicate greater adiposity and metabolic burden before conception [24, 25]. These conditions may include lower insulin sensitivity, chronic low-grade inflammation, and altered adipokine secretion. Placental hormones increase physiological insulin resistance during pregnancy. Pancreatic β-cells must increase function and insulin secretion to maintain glucose homeostasis. Pre-existing insulin resistance may reduce this compensatory reserve. The additional metabolic load of pregnancy may then contribute to GDM [26, 27].

These findings support earlier GDM prevention. Pre-pregnancy BMI should be assessed routinely in clinical practice. Women with overweight/obesity should receive priority for weight management and dietary counseling. Physical activity guidance and metabolic risk assessment are also important. After conception, early monitoring of glucose and weight may be useful for women who enter pregnancy with overweight/obesity. Other established GDM risk factors should be considered at the same time.

Independent associations of early- and mid-pregnancy GWG with GDM

We found no independent association of early- or mid-pregnancy GWG categories with GDM. This result was consistent in univariable and multivariable models. Previous findings have been inconsistent. Some studies also found no significant association between GWG categories and GDM [28]. Lifestyle interventions can reduce gestational weight gain, but they do not always reduce GDM incidence [29, 30]. Other studies linked greater weight gain before GDM screening to higher GDM risk [14, 28, 31]. Rapid gain in early or mid-pregnancy may be particularly relevant.

Several factors may explain differences across studies. Study populations differ in baseline characteristics. Methods for measuring and classifying GWG also vary. The extent of confounder adjustment is not uniform. Our null independent association does not mean that gestational weight management is unimportant. Instead, GWG may need to be interpreted together with pre-pregnancy BMI when GDM risk is assessed.

Interaction between pre-pregnancy BMI and gestational weight gain

Pre-pregnancy BMI and GWG may not act independently in relation to GDM. Yong et al. examined mediating and moderating roles of early-pregnancy BMI and GWG [32]. Their findings support consideration of pre-pregnancy weight status when gestational weight change is interpreted. Yin et al. found higher GDM risk with excessive early-pregnancy GWG and insufficient mid-pregnancy GWG [13]. Their results also suggest that associations may differ across gestational stages.

Our study adds evidence on interaction. Pre-pregnancy BMI interacted significantly with early-pregnancy GWG on the multiplicative scale. The association between pre-pregnancy overweight/obesity and GDM differed across early-pregnancy GWG categories. Additive interaction analysis also showed a negative interaction between pre-pregnancy overweight/obesity and insufficient early-pregnancy GWG. No significant interaction was found between pre-pregnancy BMI and mid-pregnancy GWG. The interaction between pre-pregnancy BMI and GWG therefore appeared more relevant in early pregnancy. GDM risk assessment should consider both pre-pregnancy BMI and early-pregnancy weight change. Neither measure should be interpreted in isolation.

The negative additive interaction requires cautious interpretation. The joint risk was lower than expected under simple additivity of the two individual effects. This finding does not mean that insufficient early-pregnancy GWG is protective. It also does not mean that lower early-pregnancy weight gain is desirable.

Joint effects of pre-pregnancy BMI and stage-specific GWG

The three-factor joint analysis provided additional information on GDM risk patterns. Six joint categories showed significantly elevated GDM risk. All six occurred among women with pre-pregnancy overweight/obesity. Women with overweight/obesity and excessive early-pregnancy GWG had higher GDM risk across all mid-pregnancy GWG categories. This pattern was seen with appropriate, insufficient, and excessive mid-pregnancy GWG. No joint category in women with normal BMI or underweight was significantly associated with GDM.

These findings suggest that pre-pregnancy overweight/obesity provides an important baseline risk context. Early- and mid-pregnancy weight-gain patterns may further shape this risk. Previous studies also suggest that the association between GWG and GDM differs by pre-pregnancy BMI [14, 20, 32, 34]. Women with overweight/obesity may already have greater adiposity and insulin resistance before pregnancy. Excessive early-pregnancy gain may further increase metabolic load [24, 25, 33, 36]. In our study, elevated risk persisted across all mid-pregnancy GWG categories in women with overweight/obesity and excessive early-pregnancy GWG. Mid-pregnancy GWG may therefore need to be interpreted together with pre-pregnancy BMI and earlier weight gain.

Clinical implications

GDM risk assessment may benefit from a stepwise approach. Pre-pregnancy BMI can provide a baseline risk marker. Early- and mid-pregnancy weight trajectories can then be added to the assessment. This approach may be more informative than using GWG categories alone. Women with pre-pregnancy overweight/obesity should receive priority for preconception weight management. Dietary counseling, physical activity guidance, and metabolic risk screening are also important. During pregnancy, weight monitoring should begin early. BMI-specific weight-gain targets should be emphasized. The negative additive interaction does not justify intentional restriction of early-pregnancy weight gain below

recommended ranges. Maternal nutrition, fetal growth, and other pregnancy outcomes must also be considered [35].

Limitations

This study has several limitations. First, the single-center retrospective design limits causal inference and generalizability. Multicenter prospective studies are needed for validation. Second, pre-pregnancy weight was partly self-reported. This may have caused misclassification of pre-pregnancy BMI and GWG. Future studies should prioritize measured preconception weight and standardized weight assessment. Third, diet, physical activity, insulin resistance, and other potential confounders were not fully captured. More comprehensive covariate collection may reduce residual confounding. Fourth, GWG was categorized as insufficient, appropriate, or excessive. This may have reduced information from the continuous measures. Future analyses could add continuous models and restricted cubic splines. Finally, some joint exposure categories included relatively few women. This may have reduced the stability of effect estimates. Larger samples and external validation are needed.

Conclusions

Pre-pregnancy overweight/obesity was associated with higher GDM risk. Pre-pregnancy BMI also interacted significantly with early-pregnancy GWG on the multiplicative scale. Six joint categories showed significantly elevated GDM risk, and all six occurred among women with pre-pregnancy overweight/obesity. The pattern was particularly consistent in women with excessive early-pregnancy GWG across different mid-pregnancy GWG categories. These findings support preconception weight management. They also support integrated, BMI-informed monitoring of gestational weight change, especially during early pregnancy.

Abbreviations

ADA, American Diabetes Association; AP, attributable proportion due to interaction; aOR, adjusted odds ratio; BMI, body mass index; CI, confidence interval; GDM, gestational diabetes mellitus; GWG, gestational weight gain; OGTT, oral glucose tolerance test; OR, odds ratio; PCOS, polycystic ovary syndrome; RERI, relative excess risk due to interaction; SI, synergy index.

Declarations

Ethics approval and consent to participate

The study was approved by the Science and Technology Ethics Review Committee for Nursing and Behavioral Medicine, Hunan University of Chinese Medicine (approval no. ZYYHLL-2026-04-005). The study followed the Declaration of Helsinki. The requirement for informed consent was waived by the ethics committee.

Consent for publication

Not applicable. The manuscript does not contain identifiable individual participant information, images, or videos.

Competing interests

The authors declare that they have no competing interests.

Patient and public involvement

Patients and members of the public were not involved in the design, conduct, reporting, or dissemination planning of this study.

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Author Contribution

HP and HY contributed equally to the study design, data collection, interpretation of results, and manuscript drafting. WZ contributed to clinical data collection and data verification. LQ contributed to statistical analysis and methodological guidance. JY contributed to the literature search and manuscript revision. RJ contributed to study conception, design, supervision, funding acquisition, and critical revision of the manuscript. All authors read and approved the final manuscript.

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Not applicable.

Data Availability

The datasets used and/or analysed during the current study are not publicly available because they contain clinical information subject to ethics approval and institutional data-management restrictions, but may be available from the corresponding author on reasonable request and with approval from the relevant institution(s).

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Figures

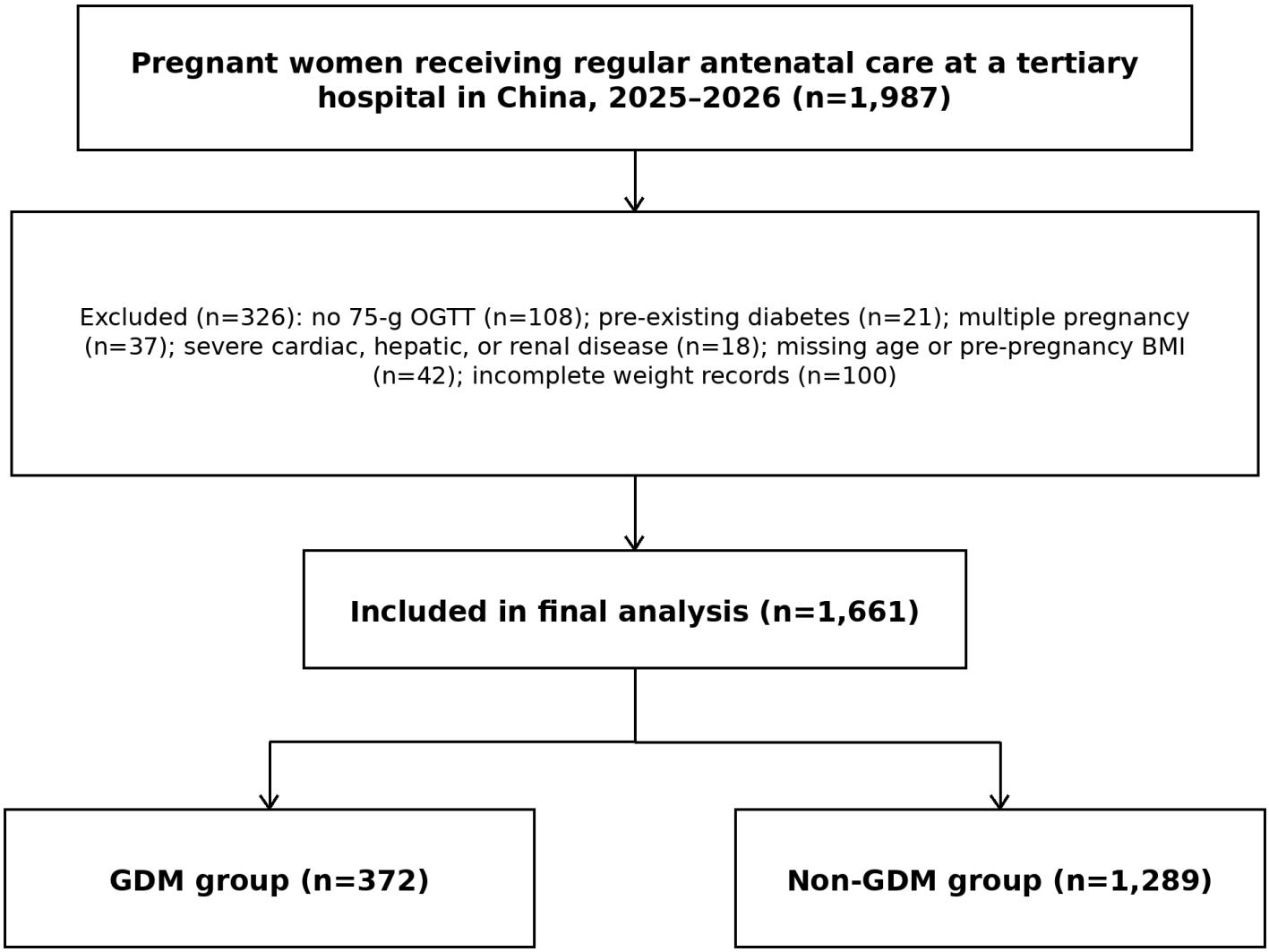


Figure 1

Participant selection flow diagram.