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Association Between Gestational Weight Gain and Maternal Outcomes in Advanced Maternal Age: A Cohort Study on Complex Risk Patterns

Kunxiu Zhang
Qikun Zhu
Hang Li
Runmei Zhou
14366469@qq.com

Minfeng Xiao

Research Article

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Abstract

Background

The association between gestational weight gain (GWG) and maternal outcomes remains controversial in women of advanced maternal age (AMA). This study aims to determine whether the association pattern in AMA women differs from that in the general population.

Methods

A single-center retrospective cohort study design was employed, including 2,164 women with singleton pregnancies of advanced maternal age who delivered between January 2023 and December 2025. Based on pre-pregnancy Body Mass Index (BMI) and the Chinese "Recommended Standards for Weight Gain during Pregnancy (2022)", total GWG was categorized into three groups: Inadequate, Adequate, and Excessive. Multivariable logistic regression models were used to analyze the associations between GWG categories and gestational diabetes mellitus (GDM), hypertensive disorders of pregnancy (HDP), and postpartum hemorrhage (PPH).

Results

Multivariable logistic regression analysis showed that, compared to the Adequate GWG group, Excessive GWG was associated with a lower risk of GDM (aOR = 0.699, 95% CI: 0.569–0.859) but a higher risk of HDP (aOR = 1.681, 95% CI: 1.170–2.430). Conversely, Inadequate GWG was associated with a higher risk of GDM (aOR = 1.861, 95% CI: 1.370–2.528). The association between GWG and PPH was not statistically significant.

Conclusion

This study identifies a complex association between GWG and maternal complications in women of advanced maternal age, particularly an inverse association between excessive weight gain and GDM risk. These findings challenge the uniform applicability of weight gain recommendations derived from the general population to older mothers. However, the inverse relationship with GDM should be interpreted with caution, potentially reflecting the impact of clinical interventions on weight trajectories. The study highlights the need for risk-stratified, individualized management strategies.

1. Background

In recent years, socioeconomic development in China has profoundly influenced women's reproductive patterns. With the continuous improvement in women's education levels and workforce participation, the age of first childbirth has been significantly delayed. Concurrently, advancements in assisted

reproductive technology (ART) have enabled more women to fulfill their desire for childbearing at an older age. National data indicates that following the implementation of the universal two-child policy, the proportion of delivering mothers aged ≥ 35 years has risen significantly (from 8.5% to 13.5%) [1], marking advanced maternal age (AMA) pregnancies as a significant component of the perinatal healthcare landscape in China. As the proportion of AMA mothers continues to rise, the associated risks of maternal complications such as gestational diabetes mellitus (GDM) and hypertensive disorders of pregnancy (HDP) increase significantly [2, 3], posing severe challenges to maternal and infant safety and driving a transformation in perinatal management towards more refined, proactive care for high-risk groups.

Gestational weight gain (GWG), one of the most intuitive and monitorable physiological indicators during pregnancy, is a critical link connecting maternal nutrition, metabolism, and pregnancy outcomes[4]. Currently, clinical practice in China relies primarily on the "Recommended Standards for Weight Gain during Pregnancy (WS/T 801–2022)" [5, 6], which is based on evidence from the general childbearing-age population. However, women of advanced maternal age exhibit significant age-related changes in metabolic, endocrine, and cardiovascular systems; their energy balance and weight regulation pathways may differ from those of younger mothers. Research confirms that AMA mothers exhibit higher insulin resistance and lipid levels as early as the first trimester [7]. Mechanistically, aging alters maternal insulin/IGF signaling and local lipid metabolism [8], potentially constituting a unique weight regulation pathway.

Although numerous studies have confirmed the general association between GWG and adverse pregnancy outcomes, recent reviews note that while behavioral interventions for GWG can effectively control weight, they have not consistently improved core maternal and infant outcomes [9], suggesting limitations in using GWG as a standalone risk predictor. A meta-analysis involving nearly 200,000 women in Europe and America indicated that while pre-pregnancy BMI can guide reference ranges for weight gain, GWG itself has limited predictive value for composite adverse outcomes; pre-pregnancy BMI remains the more significant risk predictor [10]. This suggests that even in the general population, the relationship between GWG and health outcomes is not simply linear. Therefore, a core and insufficiently answered question remains: Do the "ideal weight gain ranges" derived from the general population—and their presumed health risk associations—hold true for the AMA population, which possesses a unique physiological and metabolic foundation? Currently, large-sample studies specifically exploring the association patterns between GWG and maternal outcomes in AMA women are insufficient, with most directly applying assessment frameworks meant for the general population.

Based on this, the present study aims to systematically describe the actual association patterns between GWG (classified according to current recommended standards) and key maternal complications (GDM, HDP, PPH) in women of advanced maternal age using a large retrospective cohort analysis. The goal is to reveal specific risk associations in this group, thereby providing empirical evidence to improve targeted risk warning and individualized clinical care.

2. Materials and Methods

2.1 Study Design and Population

This was a single-center retrospective cohort study. Data were derived from the electronic medical record system of the Second Affiliated Hospital of Chongqing Medical University, China. We consecutively included all women with singleton live births who delivered between January 1, 2023, and December 31, 2025. Inclusion criteria: (1) Age at delivery ≥ 35 years; (2) Singleton pregnancy; (3) Natural conception or ART, excluding multifetal reduction cases; (4) Delivery at ≥ 24 weeks resulting in live birth or stillbirth. Exclusion criteria: (1) Multiple gestation; (2) Pre-existing diabetes, pre-pregnancy insulin resistance, chronic hypertension, or major underlying diseases (HIV/AIDS, active viral hepatitis [11–13]); (3) Substance abuse; (4) Fetal chromosomal abnormalities or severe structural malformations; (5) Incomplete key data. After screening, 2,164 women were included. This study was approved by the Ethics Committee of the Second Affiliated Hospital of Chongqing Medical University (Approval No. 2025 – 391) with a waiver of informed consent.

2.2 Sample Size Calculation

The sample size was estimated using PASS 15.0 software based on multivariable logistic regression requirements. We assumed a baseline GDM incidence of 22% (median of 20–25% in Chinese populations [14, 15]) and an excessive GWG rate of 40% [16]. With a significance level (α) of 0.05, a power (1-β) of 0.80, and an expected OR of 1.50 [17], the minimum required sample size was calculated as 1,780. Accounting for a 10% exclusion rate due to missing data, the target sample size was set at 1,980. The final inclusion of 2,164 participants met these requirements, ensuring sufficient statistical power.

2.3 Measures and Variable Definitions

Exposure Variable : Total GWG was defined as the difference between pre-delivery weight (measured upon admission for labor) and weight at the 12th week of gestation. Under the standard prenatal care protocol at our center, all pregnant women undergo their first systematic filing and weight measurement at approximately 12 gestational weeks. Therefore, the baseline weight for all included cases was obtained at a uniform gestational age (12 weeks), which minimizes variation introduced by differing initial measurement timings and ensures that total weight gain calculations are based on a consistent and comparable gestational interval. Based on pre-pregnancy Body Mass Index (BMI, kg/m²) and the *Chinese Recommended Standards for Weight Gain during Pregnancy (2022)*, GWG was categorized into three groups: Inadequate (below the recommended lower limit), Adequate (within the recommended range), and Excessive (above the recommended upper limit). Pre-pregnancy BMI was classified according to Chinese standards: Underweight (< 18.5 kg/m²), Normal weight (18.5–23.9 kg/m²), Overweight (24.0-27.9 kg/m²), and Obese (≥ 28.0 kg/m²).

Outcome Variables: (1) Hypertensive Disorders of Pregnancy (HDP) [18]: Included gestational hypertension and preeclampsia-eclampsia. To focus on new-onset disease during pregnancy, patients

with pre-existing chronic hypertension were excluded. Furthermore, to ensure the definition of "new-onset," we excluded cases during data cleaning where hypertension (systolic BP ≥ 140 mmHg and/or diastolic BP ≥ 90 mmHg) appeared before 20 weeks of gestation.(2) Gestational Diabetes Mellitus (GDM) [19]: Diagnosed based on the Oral Glucose Tolerance Test (OGTT) results using the International Association of Diabetes and Pregnancy Study Groups (IADPSG) criteria: fasting plasma glucose ≥ 5.1 mmol/L, and/or 1-hour post-load glucose ≥ 10.0 mmol/L, and/or 2-hour post-load glucose ≥ 8.5 mmol/L. (3) Postpartum Hemorrhage (PPH) [20]: Defined as blood loss ≥ 500 mL (vaginal delivery) or ≥ 1000 mL (cesarean section) within 24 hours after fetal delivery. To ensure objectivity, blood loss was assessed in our center using a combined method of volumetry (using a graduated blood collection drape) and gravimetry (weighing blood-soaked dressings and gauze).

Covariates To control for potential confounding, the following covariates were included in the analysis: maternal age (continuous), pre-pregnancy BMI (continuous), conception via Assisted Reproductive Technology (ART, binary), parity (multiparous vs. nulliparous, binary), and history of thyroid disease (binary). In this study, 'History of thyroid disease' was defined as thyroid dysfunction clearly diagnosed by an endocrinologist during or before pregnancy and documented in the electronic medical records. This included clinical hypothyroidism, subclinical hypothyroidism, and hyperthyroidism. The definition referred to authoritative guidelines for thyroid disease in pregnancy and standards used in relevant large cohort studies[21, 22]. Diagnoses were based on laboratory thyroid function tests (TSH, FT4) and clinical manifestations. This variable was included in the model as a composite binary confounder without further distinguishing between disease subtypes or control status.

2.4 Statistical Analysis

All statistical analyses were performed using R software (version 4.4.2). Continuous variables were described as mean ± standard deviation (SD) if normally distributed, or median (interquartile range, IQR) if non-normally distributed. Categorical variables were described as frequencies (percentages). Group comparisons: For normally distributed continuous variables, One-way Analysis of Variance (ANOVA) was used; for non-normally distributed continuous variables, the Kruskal-Wallis H test was used. For categorical variables, the Chi-square test was used, or Fisher's exact test when any expected cell frequency was less than 5. Additionally, to explore the trend of maternal complication rates with increasing pre-pregnancy BMI categories, a trend test was performed by entering pre-pregnancy BMI groups as an ordinal variable into logistic regression models.

Association Analysis: Multivariable logistic regression models were employed to evaluate the association between GWG categories (with the "Adequate" group as the reference) and each maternal outcome (GDM, HDP, PPH). Based on prior clinical knowledge and literature evidence, all models forced the adjustment of the following potential confounders: maternal age (continuous), parity (binary), pre-pregnancy BMI (continuous), history of thyroid disease (binary), and ART conception (binary). Results are presented as adjusted odds ratios (aOR) with 95% confidence intervals (CI).

Sensitivity Analysis: To test the robustness of the main findings, two sensitivity analyses were conducted: (1) Total GWG was entered into the model as a continuous variable, adjusting for the same covariates mentioned above; (2) To provide a more clinically meaningful interpretation, we calculated and reported the aOR for GWG "per 5 kg increase"; this unit corresponds approximately to one standard deviation of GWG in our study population, facilitating clinical comprehension.

Subgroup Analysis and Interaction Testing: To investigate whether pre-pregnancy BMI modified the association between GWG and maternal outcomes, we first included an interaction term between GWG category and pre-pregnancy BMI group in the multivariable logistic regression models and assessed its statistical significance using the likelihood ratio test. Since all interaction P-values were > 0.05, indicating no significant modification effect, subsequent analyses stratified by pre-pregnancy BMI were considered exploratory and descriptive. Their purpose was to describe the specific numerical performance of the main association across different baseline characteristics, rather than to confirm intrinsic differences between subgroups. In subgroup analyses, models within each BMI stratum were adjusted for the remaining four covariates (excluding pre-pregnancy BMI).

Statistical Significance and Multiple Comparisons: The three primary outcomes of this study (GDM, HDP, PPH) were pre-specified analysis targets based on their clinical importance. Consistent with the observational study paradigm for biologically distinct and pre-defined outcomes, we focused on reporting effect estimates and their confidence intervals rather than applying strict multiple comparison corrections (Bonferroni) to P-values. This approach was chosen to avoid being overly conservative, which could obscure findings of clinical value. All subgroup analyses are explicitly labeled as exploratory, and their results should be interpreted as descriptive data for generating future hypotheses. Statistical significance was defined as a two-sided $P < 0.05$.

3. Results

3.1 Study Population and Gestational Weight Gain Distribution

A total of 2,164 women of advanced maternal age were included in this study. As shown in Table 1, the mean maternal age was 36.77 ± 2.03 years, and the mean pre-pregnancy BMI was 22.14 ± 3.05 kg/m². According to Chinese standards, the proportions of women classified as underweight, normal weight, overweight, and obese were 7.62%, 69.73%, 17.88%, and 4.76%, respectively. The mean total gestational weight gain (GWG) was 13.10 ± 4.99 kg. Based on the *Chinese Recommended Standards for Weight Gain during Pregnancy (2022)*, 39.60% of the participants had excessive GWG, 50.55% had adequate GWG, and 9.84% had inadequate GWG. There were significant differences in the distribution of GWG across different pre-pregnancy BMI groups ($P < 0.001$).

Table 1
Characteristics of the study population and distribution of gestational weight gain by pre-pregnancy BMI

Characteristics	Total (n = 2164)	Underweight (n = 165)	Normal weight (n = 1509)	Overweight (n = 387)	Obese (n = 103)	P Value
Age (years), Median (Q1, Q3)	36.0 (35.0, 38.0)	36.0 (35.0, 38.0)	36.0 (35.0, 38.0)	36.0 (35.0, 38.0)	37.0 (35.0, 39.0)	0.006
Parity (Multiparous), n (%)	1309 (60.49%)	76 (46.06%)	918 (60.83%)	248 (64.08%)	67 (65.05%)	0.001
History of smoking, n (%)	21 (0.97%)	2 (1.21%)	13 (0.86%)	6 (1.55%)	0	0.446
History of drinking, n (%)	17 (0.79%)	2 (1.21%)	11 (0.73%)	4 (1.03%)	0	0.638
Pre-pregnancy BMI (kg/m²), Median (Q1, Q3)	21.64 (19.98, 23.73)	17.91 (17.48, 18.26)	21.09 (19.98, 22.47)	25.28 (24.46, 26.37)	29.71 (28.76, 31.55)	<0.001
History of thyroid disease, n (%)	263 (12.15%)	23 (13.94%)	168 (11.13%)	50 (12.92%)	22 (21.36%)	0.016
Conception via ART, n (%)	251 (11.60%)	19 (11.51%)	173 (11.46%)	47 (12.15%)	12 (11.65%)	0.985
Total GWG (kg), Mean ± SD	13.10 ± 4.99	14.11 ± 4.64	13.45 ± 4.60	12.00 ± 5.89	10.51 ± 5.74	<0.001
GWG Category, n (%)						<0.001
Inadequate	213 (9.84%)	33 (20.00%)	116 (7.69%)	52 (13.44%)	12 (11.65%)	
Adequate	1094 (50.55%)	94 (56.97%)	815 (54.01%)	148 (38.24%)	37 (35.92%)	
Excessive	857 (39.60%)	38 (23.03%)	578 (38.30%)	187 (48.32%)	54 (52.43%)	

Note: BMI, Body Mass Index; ART, Assisted Reproductive Technology; GWG, Gestational Weight Gain. Continuous variables with normal distribution are presented as mean ± standard deviation (SD) and compared using One-way ANOVA; non-normally distributed variables are presented as Median (Q1, Q3) and compared using the Kruskal–Wallis H test. Categorical variables are presented as frequency (percentage) and compared using the Chi-square test or Fisher's exact test (when expected frequency < 5). A two-sided $P < 0.05$ indicates statistical significance.

3.2 Incidence of Maternal Complications

As shown in Table 2, the overall incidence of GDM and HDP in this advanced maternal age cohort was 30.55% and 7.07%, respectively. Notably, the incidence of both GDM and HDP showed a significant increasing trend with higher pre-pregnancy BMI ($P < 0.001$). The incidence of PPH did not differ significantly across BMI groups ($P = 0.276$). The incidence of other complications was low, with only one case of venous thromboembolism observed (0.05%).

Table 2
Pre-pregnancy BMI and incidence of maternal complications

		Hypertensive Disorders of Pregnancy (n = 153, 7.07%)	Gestational Diabetes Mellitus (n = 661, 30.55%)	Postpartum Hemorrhage (n = 30, 1.39%)
Underweight (n = 165)		4	33	0
Normal weight (n = 1509)		84	410	21
Overweight (n = 387)		37	162	8
Obese (n = 103)		28	56	1
Group comparison P Value		<0.001	<0.001	0.276*
Trend Test				1.362(0.812, 2.285)
OR (95% CI)	2.329 (1.87, 2.90)	1.782 (1.54, 2.06)	1.362 (0.812, 2.285)	0.241

Note: Group comparisons were performed using the Chi-square test. The trend test was conducted by entering pre-pregnancy BMI groups (Underweight, Normal weight, Overweight, Obese) as an ordinal variable into a logistic regression model. The odds ratio (OR) represents the risk ratio for the outcome for each category increase in pre-pregnancy BMI.

3.3 Overall Association Between Gestational Weight Gain and Maternal Outcomes

Multivariable logistic regression analysis (Table 3) revealed distinct association patterns between total GWG and maternal outcomes. Compared to the Adequate GWG group, excessive GWG was significantly associated with a lower risk of GDM (aOR = 0.699, 95% CI: 0.569–0.859, $P < 0.001$), but simultaneously associated with a higher risk of HDP (aOR = 1.681, 95% CI: 1.170–2.430, $P = 0.005$). Conversely, inadequate GWG was associated with a higher risk of GDM (aOR = 1.861, 95% CI: 1.370–2.528, $P < 0.001$). The association between GWG categories and PPH did not reach statistical significance.

Table 3
Multivariable Logistic regression analysis of gestational weight gain and maternal outcomes

Outcome Variable	GWG Category	aOR (95% CI)	P Value
Gestational Diabetes Mellitus	Inadequate	1.861 (1.370, 2.528)	<0.001
	Adequate	1.00 (Reference)	-
	Excessive	0.699 (0.569, 0.859)	<0.001
Hypertensive Disorders of Pregnancy	Inadequate	1.107 (0.583, 1.987)	0.743
	Adequate	1.00 (Reference)	-
	Excessive	1.681 (1.170, 2.430)	0.005
Postpartum Hemorrhage	Inadequate	1.255 (0.282, 4.030)	0.728
	Adequate	1.00 (Reference)	-
	Excessive	1.567 (0.727, 3.449)	0.252

Note: aOR, adjusted Odds Ratio; CI, Confidence Interval. All models utilized multivariable logistic regression and were adjusted for maternal age, parity, pre-pregnancy BMI, history of thyroid disease, and conception via assisted reproductive technology (ART). A two-sided P < 0.05 was considered statistically significant.

3.4 Sensitivity Analysis: Association Between Continuous Gestational Weight Gain and Maternal Outcomes

To verify the robustness of the primary findings, we conducted a sensitivity analysis treating total GWG as a continuous variable. The results demonstrated that every 5 kg increase in GWG was significantly associated with a reduced risk of GDM (aOR = 0.738, 95% CI: 0.664–0.817, $P < 0.001$). This finding is highly consistent with the primary analysis, where excessive GWG was associated with a lower risk (aOR = 0.699). Regarding HDP, every 5 kg increase in GWG was similarly associated with an increased risk (aOR = 1.225, 95% CI: 1.053–1.426, $P = 0.008$). The direction of association aligned with the primary analysis, although the magnitude of the effect was slightly smaller compared to the categorical analysis (primary analysis aOR = 1.681). Both analytical approaches indicated no statistically significant association between GWG and PPH (aOR = 1.040, $P = 0.826$). Details are presented in Table 4.

Table 4
Sensitivity analysis: Association between continuous gestational weight gain and maternal outcomes

Outcome	Per 1 kg increase in GWGaOR (95% CI)	P Value	Per 5 kg increase in GWGaOR (95% CI)	P Value	Consistency with primary analysis
Gestational Diabetes Mellitus	0.941 (0.921, 0.960)	< 0.001	0.738 (0.664, 0.817)	< 0.001	Consistent
Hypertensive Disorders of Pregnancy	1.041 (1.010, 1.074)	0.008	1.225 (1.053, 1.426)	0.008	Consistent
Postpartum Hemorrhage	1.008 (0.935, 1.071)	0.826	1.040 (0.714, 1.412)	0.826	Consistent

Note: aOR, adjusted Odds Ratio; CI, Confidence Interval. All models utilized multivariable logistic regression adjusted for maternal age, parity, pre-pregnancy BMI, history of thyroid disease, and conception via ART. A two-sided P < 0.05 was considered statistically significant.

3.5 Exploratory Subgroup Analysis

To investigate whether pre-pregnancy BMI modified the association between total gestational weight gain (GWG) and maternal outcomes, we first performed formal interaction tests. In multivariable logistic regression models—adjusted for maternal age, parity, history of thyroid disease, and conception via ART—we included an interaction term between GWG category and pre-pregnancy BMI group (*GWG category × Pre-pregnancy BMI group*). Likelihood ratio tests were used to compare nested models with and without the interaction term to assess the statistical significance of the interaction.

The results showed that for gestational diabetes mellitus (GDM), the *P*-value for interaction was 0.400. For HDP and PPH, the interaction *P*-values were 0.750 and 0.798, respectively. None reached the level of statistical significance ($P > 0.05$). Comparison of model goodness-of-fit further supported this conclusion: for the GDM model, the Akaike Information Criterion (AIC) for the interaction model was 2560, while the AIC for the main effects model (without interaction) was 2554. Similarly, AIC values did not decrease with the inclusion of interaction terms for hypertensive disorders of pregnancy (Interaction AIC: 1041 vs. Main effects: 1033) or PPH (Interaction AIC: 331.3 vs. Main effects: 322.4). These results indicate that no significant modification effect of pre-pregnancy BMI on the associations between GWG and major maternal outcomes was found in this study population.

Given the absence of significant interaction effects in formal testing, the subsequent subgroup analyses stratified by pre-pregnancy BMI are considered exploratory and descriptive. The aim is to describe the specific numerical performance of the main effect (i.e., the association between excessive GWG and lower GDM risk) across populations with different baseline characteristics, rather than to confirm intrinsic differences between subgroups. Therefore, odds ratios (ORs) between different subgroups should not be directly compared.

Table 5 presents the association between GWG categories and GDM risk within different pre-pregnancy BMI subgroups. Observing the point estimates, the pattern where excessive GWG is associated with lower GDM risk persisted in the normal weight group (aOR = 0.67, 95% CI: 0.52–0.86) and the overweight group (aOR = 0.58, 95% CI: 0.37–0.91). In the underweight group, the direction of the association was consistent but not statistically significant (aOR = 0.59, 95% CI: 0.16–1.79). In the obese group, which had a smaller sample size, no clear association was observed (aOR = 1.21, 95% CI: 0.50–2.91). Conversely, inadequate GWG was generally associated with a higher risk of GDM, reaching statistical significance particularly in the underweight and normal weight groups.

Table 5
Exploratory analysis: Association between gestational weight gain and gestational diabetes mellitus in different pre-pregnancy BMI subgroups

Pre-pregnancy BMI Group	GWG Category	Total cases (GDM cases)	aOR (95% CI)	P Value
Underweight	Inadequate	33	3.38 (1.36, 8.43)	0.008
	Adequate (Ref)	94	1.00	-
	Excessive	38	0.59 (0.16, 1.79)	0.385
Normal weight	Inadequate	116	1.87 (1.25, 2.79)	0.002
	Adequate (Ref)	815	1.00	-
	Excessive	578	0.67 (0.52, 0.86)	0.002
Overweight	Inadequate	52	1.87 (0.96, 3.57)	0.067
	Adequate (Ref)	148	1.00	-
	Excessive	187	0.58 (0.37, 0.91)	0.019
Obese	Inadequate	12	0.91 (0.23, 3.55)	0.890
	Adequate	37	1.00	-
	Excessive	54	1.21 (0.50, 2.91)	0.672

Note: aOR, adjusted Odds Ratio; CI, Confidence Interval. Models within all subgroups were adjusted for maternal age, parity, history of thyroid disease, and conception via assisted reproductive technology (ART). The "Adequate" GWG category served as the reference within each subgroup. P-values < 0.05 are considered statistically significant and are shown in bold. This table represents an exploratory description following non-significant formal interaction tests; aORs across subgroups should not be directly compared.

4. Discussion

Through a large-scale retrospective cohort analysis, this study reveals an association pattern between GWG and maternal complications in women of advanced maternal age that diverges from traditional understanding. Specifically, compared to the adequate GWG group, excessive GWG was associated with a lower risk of GDM but simultaneously a higher risk of HDP. Conversely, inadequate GWG was associated with an increased risk of GDM. This complex finding challenges the linear hypothesis widely applicable to the general childbearing population—that "greater weight gain equals higher metabolic risk" [23]—and suggests that in the unique physiological state of advanced maternal age, more complex threshold associations may exist between weight changes and maternal health outcomes. Our findings underscore the potential limitations of directly extrapolating uniform weight management guidelines derived from the general population to women of AMA, emphasizing the necessity for individualized assessment in clinical practice that considers the unique physiological background of this demographic.

Mechanisms of the Non-linear Association between GWG and GDM Risk

The significant association between inadequate GWG and increased GDM risk (aOR = 1.861) may be rooted in the interaction between gestational metabolic physiology and advanced maternal age. Successful glycemic regulation during pregnancy relies on adequate energy reserves (hepatic glycogen) established early and the compensatory capacity of the maternal pancreas to counter physiological insulin resistance induced by placental hormones (human placental lactogen) in the mid-to-late trimesters [24, 25]. For women of advanced maternal age, inadequate GWG may disrupt this metabolic balance through two pathways: (1) Depletion of reserves: Inadequate weight gain directly reflects insufficient caloric and nutritional intake, preventing the establishment of sufficient metabolic reserves, such as hepatic glycogen, in early pregnancy; (2) Compressed compensatory capacity: Advanced age is often accompanied by age-related declines in insulin sensitivity and β-cell function [7], reducing the maternal pancreatic compensatory ability and thereby significantly increasing GDM risk. Conversely, the observation that excessive GWG is associated with a reduced risk of GDM (aOR = 0.699) requires cautious interpretation and likely involves reverse causality. In clinical practice, women diagnosed with GDM (typically at 24–28 weeks) immediately undergo medical nutrition therapy and strict lifestyle interventions to control hyperglycemia, which significantly limits their subsequent weight gain in the third trimester. Therefore, "lower" GWG in the GDM group may be a consequence of the disease management rather than a protective factor. Furthermore, women who maintained excessive weight gain without developing hyperglycemia may possess inherently robust pancreatic β-cell function and insulin sensitivity, allowing them to tolerate the metabolic stress of adiposity without decompensating into GDM.

GWG and HDP Risk: Mechanisms and Clinical Implications

Consistent with previous studies [26, 27], excessive GWG in this study was significantly associated with an increased risk of hypertensive disorders of pregnancy (aOR = 1.681, 95% CI: 1.170–2.430). Potential pathophysiological mechanisms include: (1) Inflammation and endothelial dysfunction: The obesogenic

metabolic environment caused by excessive weight gain can induce adipokine dysregulation, insulin resistance, and chronic low-grade systemic inflammation, leading to vascular endothelial dysfunction, a core pathological feature of preeclampsia [26]. (2) Increased volume load: Weight gain exacerbates physiological volume expansion. Research indicates that excessive gestational volume load superimposed on an already compromised cardiovascular system forms a critical hemodynamic basis for HDP by directly increasing cardiac preload [28]. Notably, inadequate GWG did not reduce HDP risk in this study. This suggests that HDP occurrence may not be simply linearly related to the numerical value of weight gain. Instead, it implies that in the context of obesity or excessive gain, adipose tissue dysfunction itself—and the resulting chronic inflammation and metabolic disorder—may be a more central pathogenic pathway than simple weight change. Even if GWG is not excessive, women with underlying pathological endocrine and inflammatory states remain at high risk for HDP. Therefore, prevention strategies for high-risk groups should transcend simple weight management and integrate early blood pressure monitoring, vascular function assessment, and screening for inflammatory markers (high-sensitivity C-reactive protein, adiponectin) to achieve more precise risk stratification and intervention.

The interaction analysis in this study did not find a significant modifying effect of pre-pregnancy BMI on the main associations ($P > 0.05$). However, the instability of estimates observed in the pre-pregnancy obesity subgroup (wide confidence intervals) mainly reflects insufficient statistical power due to limited sample size in that subgroup, rather than necessary biological heterogeneity. This suggests that in the context of the profound metabolic dysregulation associated with obesity, the marginal effect of GWG might be masked or reshaped, warranting specific exploration in future large-sample studies. The study's conclusions regarding GWG-complication association patterns are primarily based on the overall population and subgroups with adequate sample sizes.

This study has several limitations. First, the retrospective observational design cannot fully exclude the potential influence of unmeasured confounders (e.g., diet, physical activity, and socioeconomic status). Second, we analyzed total GWG rather than trimester-specific gain. As GDM diagnosis and subsequent dietary interventions can alter weight gain trajectories in late pregnancy, using total GWG may introduce therapeutic bias, contributing to the observed inverse association between excessive GWG and GDM. Third, as a single-center study, the sample was derived from a tertiary hospital, potentially limiting the generalizability of results to community populations. Fourth, total GWG was calculated using weight measured at 12 weeks of gestation as the baseline. While this ensured consistency in measurement timing—a common practice in clinical research—it implies that this "baseline" weight already included physiological weight gain from the first trimester[29]. Consequently, our calculated total GWG systematically underestimates the actual weight gain from the true pre-pregnancy state. In epidemiology, such non-differential measurement error of the exposure variable typically biases effect estimates toward the null. This means that the significant association observed in this study ("excessive GWG associated with reduced GDM risk", aOR = 0.699) likely represents an underestimation of the true effect; this bias logically strengthens the robustness of the primary finding rather than weakening it. Finally, we did not perform statistical corrections for multiple comparisons; although the primary outcomes were

pre-specified, this may slightly increase the risk of Type I error, and results from exploratory subgroup analyses should be interpreted with caution. Future research requires multi-center, prospective designs incorporating true pre-pregnancy or very early pregnancy weight as a precise baseline, combined with body composition measurements and metabolomic markers, to validate our findings and elucidate causal mechanisms.

The findings have clear implications for clinical care and public health policy. Currently, China widely adopts the *Recommended Standards for Weight Gain during Pregnancy (WS/T 801–2022)* for weight management. However, this study finds that current weight gain recommendations have limited value for predicting and managing complications in the specific population of women of advanced maternal age. We recommend promoting a risk-stratified, individualized management pathway: at the first prenatal visit, integrate assessments of pre-pregnancy BMI, baseline metabolic markers (fasting glucose and insulin levels), and vascular function indicators (baseline blood pressure). Based on this, perform initial risk stratification: for women with relatively normal pre-pregnancy metabolic status, moderate weight gain (even slightly exceeding guideline upper limits) may be metabolically acceptable, provided blood pressure is strictly monitored; for women who are already overweight/obese or show signs of metabolic abnormality, strict control of weight gain velocity to reduce cardiovascular risk should be the primary goal. Future development of risk prediction tools integrating age, pre-pregnancy metabolic profiles, and dynamic weight changes will enable more precise guidance [30, 31].

At the public health level, given the rising proportion of women of advanced maternal age in China, our results call for refining perinatal healthcare strategies for this population. First, national gestational weight management guidelines should consider providing more elastic recommendation ranges or supplementary stratified guidance for women of advanced maternal age; recent research also suggests that "modified guidelines" combining the strengths of different standards may be more suitable for specific populations [32]. Second, pre-conception care should be vigorously promoted, integrating pre-pregnancy weight and metabolic management into community health promotion programs to optimize the gestational starting state at the source. Finally, within prenatal care systems and healthcare provider training, there should be an emphasis on enhancing capabilities for multi-dimensional, integrated risk assessment for women of advanced maternal age—moving beyond a focus on a single weight indicator—to build a more efficient and resilient maternal and child health service system.

5. Conclusion

This cohort study on women of advanced maternal age reveals that the pattern of association between GWG and maternal complications differs significantly from that of the general childbearing-age population, showing clinically significant heterogeneity. Core findings indicate that excessive GWG is associated with a lower risk of GDM but at the same time a higher risk of HDP, whereas inadequate weight gain is explicitly linked to an increased risk of GDM. These findings challenge the traditional linear "weight gain-metabolic risk" framework established from studies of the general population, highlighting the unique physiological and metabolic background of the advanced maternal age cohort. Our study

suggests that for women of advanced maternal age, a single, universal GWG recommendation may be insufficient for accurately predicting or managing complication risks. Clinical practice and public health policy should shift toward strategies that integrate pre-pregnancy metabolic characteristics with risk-stratified management. Such an approach is essential to achieve individualized health management goals and effectively address the increasingly prominent health challenges of advanced maternal age pregnancies in China.

Declarations

Ethics approval and consent to participate

Ethical approval for this retrospective study was granted by the Ethics Committee of the Second Affiliated Hospital of Chongqing Medical University (Approval No. 2025-391). The requirement for informed consent was waived by the same committee because the research involved the analysis of existing, anonymized patient data, and the study presented no more than minimal risk to the participants.

Consent for publication

Not applicable

Data availability statement

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request

Conflict of interest statement

All authors declare that they have no conflict of interest

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Authors' contributions

Kunxiu Zhang and Qikun Zhu conceived and designed the study. Minfeng Xiao and Hang Li collected and organized the data. Kunxiu Zhang, Qikun Zhu and Hang Li analyzed and interpreted the data. Kunxiu Zhang and Qikun Zhu drafted the manuscript. Kunxiu Zhang and Runmei Zhou revised and finalized the manuscript. All authors read and approved the manuscript.

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