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Association of gestational weight gain patterns with preterm birth subtypes in a population based cohort study from China

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This study examined the association between gestational weight gain (GWG) patterns and preterm birth (PTB) subtypes using data from a registry system in Wuhan, China. A total of 57,138 women with live singleton births were included. Total GWG in the first and second trimesters was categorized as insufficient, appropriate, or excessive based on Chinese guidelines, and weekly early GWG (<20 weeks; eGWG) was classified into Class I (<100 g/week), Class II (100–399 g/week), and Class III (≥400 g/week). Multiple logistic regression analyses assessed the relationships between GWG patterns and PTB subtypes, including spontaneous PTB, medically indicated PTB, and preterm premature rupture of membranes (PPROM), and adjusted for covariates such as age, education, pregnancy, parity, and offspring sex. Subgroup analyses were conducted by pre-pregnancy BMI categories (underweight: <18.5 kg/m², normal weight: 18.5–23.9 kg/m², overweight/obesity: ≥24 kg/m²). Results showed that underweight women with excessive GWG or Class III eGWG had increased risks of all PTB subtypes. Normal weight women with excessive or Class III eGWG, as well as insufficient or Class I eGWG, exhibited elevated risks for all PTB types. Overweight/obesity women with insufficient or Class I eGWG were at higher risks for spontaneous PTB and PPROM. These findings underscore the importance of optimal GWG across all BMI categories to mitigate PTB risks, highlighting the need for tailored prenatal weight management strategies.

Abbreviations

BMI	Body mass index
CI	Confidence interval
eGWG	Early gestational weight gain
GWG	Gestational weight gain
OR	Odds ratio
PTB	Preterm birth
PPROM	Preterm premature rupture of membrane

Preterm birth (PTB), defined as the delivery of a born infant before 37 completed gestational weeks[1], is the leading cause of neonatal mortality and morbidity worldwide[2] and has been reported to be strongly associated with long-term health problems such as neurological disabilities and various chronic diseases[3,4]. In recent decades, the burden of PTB has been substantial and increasing[5]. Therefore, it is crucial to identify the potential modifiable risk factors to prevent PTB. The etiology of PTB is multifactorial and involves a complex interplay of genetic, environmental, and socioeconomic factors[6]. While significant progress has been made in understanding these contributors, many aspects remain under investigation.

Several previous studies have indicated that maternal overweight/obesity is one potentially modifiable risk factor for PTB[7,8] and thus provided a target for intervention of PTB during pre-conception care. Besides, as weight control is considered more feasible during pregnancy than before conception, there is increasing concern about the association of gestational weight gain (GWG) with PTB. However, conclusions of previous investigations have been inconsistent, as several studies reported an association of lower GWG with an elevated risk of PTB[9]. In contrast, some studies indicated that the risk of PTB increased with higher GWG[10].

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Most previous studies only evaluated the total GWG throughout pregnancy, which may lead to biased associations because GWG differs by term and preterm birth[11] and is not linear throughout pregnancy[12]. The early GWG (<20 weeks gestation, eGWG) was considered to be critical for embryogenesis and fetal growth[13]. However, few studies have specifically examined eGWG related to PTB. Furthermore, PTB is a heterogeneous condition, but few studies have examined whether associations of GWG with PTB differ according to different subtypes of PTB, such as spontaneous PTB, preterm premature rupture of membrane (PPROM), and medically indicated PTB. Besides, most of the previous studies were conducted in developed countries. However, in developing countries, women of reproductive age generally have a lower body mass index (BMI) than those in developed countries[14] and was less investigated. Furthermore, existing GWG guidelines, such as those from the Institute of Medicine (IOM)[12] of the USA, may not be fully applicable to Chinese women due to differences in body composition and lifestyle.

Therefore, the relationship between GWG patterns and PTB subtypes remains inadequately explored, particularly in the context of Chinese women and the recommended values outlined in Chinese guidelines. To address this gap, we conducted a retrospective cohort study involving 57,138 women in China, utilizing data from a registration system. This study aimed to investigate the association between total GWG in the first and second trimesters, and weekly eGWG with the risk of PTB subtypes in singleton pregnancies.

Results

General characteristics of the study subjects

Table 1 presents the maternal characteristics of women in the study. Of the 57,138 women, 1999 (3.5%) gave birth to a PTB infant. Among all the PTBs, 577 (28.8%) were spontaneous PTB, 567 (28.3%) were PPROM, and 855 (42.7%) were medically indicated PTB. The total GWG of most pregnant women (61.9%) in the first and

Maternal characteristic	PTB No (n = 55139)	PTB Yes (n = 1999)	Total (n = 57138)
Age at delivery (years)			
< 25	10,143 (18.4)	303 (15.2)	10,446 (18.3)
25–29	28,733 (52.1)	891 (44.6)	29,624 (51.8)
30–34	12,761 (23.1)	584 (29.2)	13,345 (23.4)
≥ 35	3502 (6.4)	221 (11.1)	3723 (6.5)
Education level			
Less than high school	6601 (12.0)	229 (11.5)	6830 (12.0)
High school	24,507 (44.4)	908 (45.4)	25,415 (44.5)
College	21,224 (38.5)	768 (38.4)	21,992 (38.5)
Advanced degree	2807 (5.1)	94 (4.7)	2901 (5.1)
Gravidity			
1	28,565 (51.8)	1033 (51.7)	29,598 (51.8)
2	14,263 (25.9)	464 (23.2)	14,727 (25.8)
≥ 3	12,311 (22.3)	502 (25.1)	12,813 (22.4)
Parity			
Nulliparous	46,149 (83.7)	1597 (79.9)	47,746 (83.6)
Multiparous	8990 (16.3)	402 (20.1)	9392 (16.4)
Offspring gender			
Male	29,160 (59.7)	1194 (52.9)	30,354 (53.1)
Female	25,979 (40.3)	804 (47.1)	26,784 (46.9)
Pre-pregnancy BMI (kg/m^2)			
Underweight (< 18.5)	10,038 (18.2)	398 (19.9)	10,436 (18.3)
Normal (18.5–23.9)	42,062 (76.3)	1486 (74.3)	43,548 (76.2)
Overweight (24-27.9)	2720 (4.9)	103 (5.2)	2823 (4.9)
Obesity (≥ 28)	319 (0.6)	12 (0.6)	331 (0.6)
Total GWG in the first and second trimesters			
Insufficient	4081 (7.4)	207 (10.4)	4288 (7.5)
Adequate	17,046 (30.9)	462 (23.1)	17,508 (30.6)
Excessive	34,012 (61.7)	1330 (66.5)	35,342 (61.9)
Average weekly eGWG (g/week) (n = 55514)			
Class I (< 100)	8113 (15.2)	379 (19.4)	8492 (15.3)
Class II (100–399)	36,798 (68.8)	1045 (53.0)	37,833 (68.3)
Class III (≥ 400)	8549 (16.0)	540 (27.6)	9089 (16.4)

Table 1. Maternal characteristics of 57,138 women, N (%). *PTB* preterm birth, *BMI* body mass index.

Variables	PTB			Spontaneous PTB			PPROM			Medically indicated PTB		
	n (%)	Crude OR (95% CI)	*P*	*n* (%)	Crude OR (95% CI)	*P*	*n* (%)	Crude OR (95% CI)	*p*	*n* (%)	Crude OR (95% CI)	*P*
Total GWG in the first and second trimesters												
Insufficient, $n = 4288$	207 (4.8)	1.92 (1.43–2.59)	< 0.001	65 (1.5)	1.92 (1.43–2.59)	< 0.001	51 (1.2)	1.53 (1.11–2.11)	0.010	91 (2.1)	2.02 (1.57–2.60)	< 0.001
Adequate, $n = 17{,}508$	462 (2.6)	1.00 (Reference)		139 (0.8)	1.00 (Reference)		137 (0.8)	1.00 (Reference)		186 (1.1)	1.00 (Reference)	
Excessive, $n = 35{,}342$	1330 (3.8)	1.33 (1.10–1.62)	0.004	373 (1.1)	1.33 (1.10–1.62)	0.004	379 (1.1)	1.37 (1.13–1.67)	0.001	578 (1.6)	1.55 (1.31–1.83)	< 0.001
Average weekly eGWG (g/week)												
Class I (< 100), $n = 8492$	379 (4.5)	1.66 (1.47–1.87)	< 0.001	116 (1.4)	1.63 (1.32–2.02)	< 0.001	108 (1.3)	1.77 (1.41–2.21)	< 0.001	155 (1.8)	1.57 (1.31–1.89)	< 0.001
Class II (100 g-399), $n = 37{,}833$	1035 (2.7)	1.00 (Reference)		319 (0.8)	1.00 (Reference)		274 (0.7)	1.00 (Reference)		442 (1.2)	1.00 (Reference)	
Class III (≥ 400), $n = 9089$	540 (5.9)	2.45 (2.02–2.50)	< 0.001	132 (1.5)	1.73 (1.41–2.13)	< 0.001	551 (1.0)	2.60 (2.14–3.15)	< 0.001	239 (2.6)	2.29 (1.95–2.68)	< 0.001

Table 2. Associations of GWG patterns with PTB subtypes in the crude model. *PTB* preterm birth, *GWG* gestational weight gain, *eGWG* early GWG, *OR* odds ratio, *CI* confidence interval.

Variables	PTB			Spontaneous PTB			PPROM			Medically indicated PTB		
	n (%)	Adjusted OR (95% CI)	*P*	*n* (%)	Adjusted OR (95% CI)	*P*	*n* (%)	Adjusted OR (95% CI)	*p*	*n* (%)	Adjusted OR (95% CI)	*P*
Total GWG in the first and second trimesters												
Insufficient, $n = 4288$	207 (4.8)	1.88 (1.59–2.22)	< 0.001	65 (1.5)	1.89 (1.41–2.55)	< 0.001	51 (1.2)	1.53 (1.10–2.11)	0.011	91 (2.1)	2.06 (1.60–2.66)	< 0.001
Adequate, $n = 17{,}508$	462 (2.6)	1.00 (Reference)		139 (0.8)	1.00 (Reference)		137 (0.8)	1.00 (Reference)		186 (1.1)	1.00 (Reference)	
Excessive, $n = 35{,}342$	1330 (3.8)	1.43 (1.28–1.60)	< 0.001	373 (1.1)	1.35 (1.11–1.65)	0.002	379 (1.1)	1.35 (1.11–1.64)	0.003	578 (1.6)	1.52 (1.29–1.80)	< 0.001
Average weekly eGWG (g/week)												
Class I (< 100), $n = 8492$	379 (4.5)	1.70 (1.50–1.92)	< 0.001	116 (1.4)	1.67 (1.35–2.07)	< 0.001	108 (1.3)	1.78 (1.42–2.22)	< 0.001	155 (1.8)	1.62 (1.35–1.95)	< 0.001
Class II (100 g-399), $n = 37{,}833$	1035 (2.7)	1.00 (Reference)		319 (0.8)	1.00 (Reference)		274 (0.7)	1.00 (Reference)		442 (1.2)	1.00 (Reference)	
Class III (≥ 400), $n = 9089$	540 (5.9)	2.21 (1.99–2.46)	< 0.001	132 (1.5)	1.73 (1.41–2.13)	< 0.001	551 (1.0)	2.55 (2.10–3.10)	< 0.001	239 (2.6)	2.24 (1.90–2.63)	< 0.001

Table 3. Associations of GWG patterns with PTB subtypes in the adjusted model. Models were adjusted for maternal age at delivery, education level, parity, and offspring gender. *PTB* preterm birth, *GWG* gestational weight gain, *eGWG* early GWG, *OR* odds ratio, *CI* confidence interval.

second trimesters is excessive, and the average weekly eGWG of most pregnant women (68.3%) ranges from 100 to 399 g.

Association of weight gain patterns with PTB subtypes

Table 2 (crude model) and Table 3 (adjusted model) shows the associations of total GWG in the first and second trimesters, and weekly eGWG with PTB subtypes.

In the adjusted model, compared with women who had a total GWG in the first and second trimesters within the Chinese recommendation, women who were below and above the recommended value had an increased risk of PTB (below, OR: 1.88, 95% CI: 1.59–2.22, $P < 0.001$; above, OR: 1.43, 95% CI: 1.28–1.60, $P < 0.001$). When the outcomes were stratified according to different PTB subtypes, the aforementioned associations remained statistically significant, with the highest risk observed in medically indicated PTB.

In the adjusted model, compared with women with weekly eGWG of 100–399 g (Class II), pregnant women with a weekly eGWG of < 100 g (Class I) and ≥ 400 g (Class III) had a higher risk of PTB (Class I, OR: 1.70, 95% CI: 1.50–1.92, $P < 0.001$; Class III, OR: 2.21, 95% CI: 1.99–2.46, $P < 0.001$). When analyzing different subtypes of PTB as the outcome, the associations described above retained their statistical significance, with the highest risk observed in PPROM.

Association of weight gain patterns with PTB subtypes in pregnant women with different pre-pregnancy BMI

Further, we examined the associations of total GWG in the first and second trimesters, and weekly eGWG with PTB subtypes stratified by pre-pregnancy BMI in both crude (Table 4) and adjusted (Table 5) models.

In normal (pre-pregnancy BMI: 18.5–23.9 kg/m^2) pregnant women, except for the association between total GWG and PPROM, which did not reach statistical significance (OR: 1.24, 95% CI: 0.99–1.54, $P = 0.059$), both insufficient and excessive weight gain—whether measured as total GWG in the first and second trimesters or as weekly eGWG—were statistically associated with an increased risk of all three PTB subtypes.

Among underweight (pre-pregnancy BMI < 18.5 kg/m^2) pregnant women, excessive weight gain (both total GWG in the first and second trimesters and weekly eGWG) was positively associated with an increased risk of all subtypes of PTB, while insufficient weight gain showed no significant association. However, among overweight/obesity (pre-pregnancy BMI ≥ 24 kg/m^2) pregnant women, only insufficient total GWG during the first and second trimesters was associated with an increased risk of spontaneous PTB (OR: 3.75, 95% CI: 1.23–11.43, $P = 0.020$) and PPROM (OR: 3.80, 95% CI: 1.25–11.49, $P = 0.018$).

Discussion

In this cohort study conducted among Chinese women based on a registry system, we found that total GWG in the first and second trimesters and weekly eGWG were associated with an increased risk of PTB as well as its subtypes. When stratified by pre-pregnancy BMI, excessive weight gain in underweight women, insufficient or excessive weight gain in normal-weight women, and insufficient weight gain in overweight/obese women were identified as risk factors for PTB and its subtypes.

GWG is a critical modifiable factor influencing perinatal maternal and neonatal outcomes and appropriate GWG has been implicated as a causal factor in various adverse pregnancy outcomes, including PTB[15,16]. According to published studies, the association between insufficient GWG and an increased risk of PTB is well-established[17–21,9], while the relationship between excessive GWG and PTB remains controversial. The study by Pigatti Silva et al.[18] identified excessive GWG as a risk factor for PTB, which is consistent with our findings. However, other studies[19–22] have reported that excessive GWG may act as a protective factor against PTB. For instance, a study conducted in China[20] demonstrated an inverse association between GWG and PTB (OR: 0.81, 95% CI: 0.72–0.91). Similarly, a study from Puerto Rico[21] indicated that excessive GWG reduced the risk of both moderate PTB (OR: 0.77, 95% CI: 0.67–0.88) and late PTB (OR: 0.93, 95% CI: 0.88–0.98) among overweight/obese pregnant women. The conflicting findings may be attributed to the fact that these studies did not account for the differences in the duration of GWG between preterm and term delivery groups[12]. Specifically, PTB inherently shortens the time available for weight gain, potentially leading to lower total GWG among women delivering preterm, which could confound the observed association between GWG and PTB.

Additionally, pre-pregnancy BMI plays a significant role in the relationship between GWG and PTB. Both Chinese[23] and IOM[12] guidelines specify distinct recommended GWG ranges based on pre-pregnancy BMI categories. Previous studies[18,20] have shown that the impact of GWG on PTB risk differs according to pre-pregnancy BMI. In line with this, our study found that underweight women with excessive GWG and overweight/obese women with insufficient GWG had a higher risk of PTB. It is worth noting that, unlike these two studies[18,20] conducted in East Asian populations which applied the IOM recommendations[12]—a standard more suitable for White populations—our study utilized the Chinese guidelines[23] to classify both pre-pregnancy BMI categories and GWG ranges.

Moreover, eGWG was critical for embryogenesis and fetal growth[12]. However, few studies have specifically examined eGWG related to PTB. Therefore, in this study, we also investigated the association of weekly eGWG with PTB, and our results indicated that low or high weekly eGWG was significantly associated with a higher risk of all types of PTB. Specifically, high weekly eGWG was most strongly linked to PTB in underweight women, but not significantly associated in overweight/obese women. These findings highlight the clinical importance of managing early gestational weight gain, particularly in underweight and normal-weight women, to reduce the risk of PTB.

While GWG in the first half of pregnancy is mainly the result of maternal tissue deposition and placental growth, gains from that point on until the end of pregnancy might be influenced by the accumulation of amniotic fluid. Inappropriate GWG is associated with inflammatory up-regulation through increased production of

Variables		PTB			Spontaneous PTB			PPROM			Medically indicated PTB		
		n (%)	Crude OR (95% CI)	*P*	*n* (%)	Crude OR (95% CI)	*P*	*n* (%)	Crude OR (95% CI)	*P*	*n* (%)	Crude OR (95% CI)	*P*
Total GWG in the first and second trimesters													
Underweight (< 18.5 kg/m²)	Insufficient	31 (2.7)	1.24 (0.80–1.92)	0.334	12 (1.1)	1.46 (0.71-3.00)	0.301	5 (0.4)	0.71 (0.26–1.94)	0.507	14 (1.2)	1.42 (0.73–2.76)	0.298
	Adequate	61 (2.2)	1.00 (Reference)	-	20 (0.7)	1.00 (Reference)	-	17 (0.6)	1.00 (Reference)	-	24 (0.9)	1.00 (Reference)	-
	Excessive	306 (4.7)	2.18 (1.65–2.88)	< 0.001	97 (1.5)	2.07 (1.28–3.36)	0.003	86 (1.3)	2.16 (1.28–3.64)	0.004	123 (1.9)	2.19 (1.41–3.40)	0.001
Normal (18.5–23.9 kg/m²)	Insufficient	157 (5.4)	2.08 (1.72–2.51)	< 0.001	46 (1.6)	1.97 (1.40–2.79)	< 0.001	39 (1.3)	1.65 (1.15–2.38)	0.007	72 (2.5)	2.39 (1.80–3.18)	< 0.001
	Adequate	374 (2.7)	1.00 (Reference)	-	113 (0.8)	1.00 (Reference)	-	114 (0.8)	1.00 (Reference)	-	147 (1.0)	1.00 (Reference)	-
	Excessive	955 (3.6)	1.36 (1.21–1.54)	< 0.001	265 (1.0)	1.24 (1.00-1.55)	0.056	271 (1.0)	1.26 (1.01–1.57)	0.041	419 (1.6)	1.51 (1.25–1.83)	< 0.001
Overweight/obesity (≥ 24 kg/m²)	Insufficient	19 (8.3)	2.26 (1.23–4.14)	0.009	7 (3.1)	3.65 (1.21–10.97)	0.021	7 (3.1)	3.65 (1.21–10.97)	0.021	5 (2.2)	1.02 (0.37–2.84)	0.971
	Adequate	27 (3.9)	1.00 (Reference)	-	6 (0.9)	1.00 (Reference)	-	6 (0.9)	1.00 (Reference)	-	15 (2.1)	1.00 (Reference)	-
	Excessive	69 (3.1)	0.80 (0.51–1.26)	0.328	11 (0.5)	0.58 (0.21–1.56)	0.277	22 (1.0)	1.16 (0.47–2.86)	0.755	36 (1.6)	0.75 (0.41–1.38)	0.356
Average weekly eGWG (g/week)													
Underweight (< 18.5 kg/m²)	Class I (< 100 g)	29 (2.6)	0.98 (0.66–1.47)	0.934	9 (0.8)	0.81 (0.40–1.63)	0.558	9 (0.8)	1.29 (0.63–2.66)	0.490	11 (1.0)	0.96 (0.51–1.83)	0.909
	Class II (100–399 g)	173 (2.6)	1.00 (Reference)	-	65 (1.0)	1.00 (Reference)	-	41 (0.6)	1.00 (Reference)	-	67 (1.0)	1.00 (Reference)	-
	Class III (≥ 400 g)	193 (8.2)	3.32 (2.69–4.10)	< 0.001	54 (2.3)	2.36 (1.64–3.40)	< 0.001	57 (2.4)	3.97 (2.65–5.95)	< 0.001	82 (3.5)	3.52 (2.54–4.88)	< 0.001
Normal (18.5–23.9 kg/m²)	Class I (< 100 g)	313 (4.8)	1.80 (1.57–2.06)	< 0.001	97 (1.5)	1.80 (1.42–2.28)	< 0.001	87 (1.3)	1.84 (1.43–2.36)	< 0.001	129 (2.0)	1.71 (1.40–2.10)	< 0.001
	Class II (100–399 g)	794 (2.7)	1.00 (Reference)	-	242 (0.8)	1.00 (Reference)	-	213 (0.7)	1.00 (Reference)	-	339 (1.2)	1.00 (Reference)	-
	Class III (≥ 400 g)	337 (5.3)	2.01 (1.77–2.29)	< 0.001	76 (1.2)	1.46 (1.12–1.89)	0.005	109 (1.7)	2.39 (1.89–3.01)	< 0.001	152 (2.4)	2.10 (1.73–2.54)	< 0.001
Overweight/obesity (≥ 24 kg/m²)	Class I (< 100 g)	37 (4.7)	1.29 (0.86–1.95)	0.220	10 (1.3)	1.97 (0.85–4.58)	0.115	12 (1.5)	1.42 (0.69–2.91)	0.344	15 (1.9)	0.98 (0.53–1.80)	0.944
	Class II (100–399 g)	68 (3.6)	1.00 (Reference)	-	12 (0.6)	1.00 (Reference)	-	20 (1.1)	1.00 (Reference)	-	36 (1.9)	1.00 (Reference)	-
	Class III (≥ 400 g)	10 (2.7)	0.73 (0.37–1.43)	0.355	2 (0.5)	0.83 (0.17–3.74)	0.811	3 (0.8)	0.75 (0.22–2.53)	0.640	5 (1.3)	0.69 (0.27–1.77)	0.441

Table 4. Associations of GWG patterns with PTB subtypes stratified by pre-pregnacy BMI in the crude model.

adipokines by adipose tissue and augmented systemic secretion of pro-inflammatory cytokines, which may contribute to the biological pathway of PTB[24]. Another potential biological pathway is that inappropriate GWG may disrupt maternal endocrine homeostasis. Excessive weight gain during early pregnancy can disrupt metabolic homeostasis, leading to insulin resistance, hyperglycemia, and dyslipidemia, which may impair placental function and increase the risk of PTB[6].

Our findings suggest that public health recommendations should emphasize personalized GWG targets based on pre-pregnancy BMI. For underweight women, avoiding excessive GWG during early pregnancy may reduce PTB risk, while overweight/obese women should be encouraged to achieve adequate GWG to prevent adverse outcomes. Prenatal care programs and community-based interventions could play a key role in supporting women in achieving these goals.

This study has several notable strengths. First, it mitigates potential confounding due to differences in the duration of GWG between preterm and term birth populations. Second, it employs GWG recommendations specifically tailored to the Chinese population, ensuring more accurate classification of GWG categories. We also hope that this study can provide valuable insights for future research in low- and middle-income countries. Third, the large sample size allows for in-depth stratified analyses based on PTB subtypes and pre-pregnancy BMI categories.

However, this study also has certain limitations. A potential limitation of the study is that our data relies on a self-reported pre-pregnancy weight, which could be underestimated, and the potential misclassification bias may exist. However, previous studies suggest that the resulting BMI category from self-reported data rarely alters, and the self-reported weight may be considered an acceptable substitute for actual measurements[25,26]. Another limitation is that even if we adjusted for several potential confounders, residual confounding from unmeasured factors (e.g., diet or physical activity) cannot be ruled out. Future studies with more comprehensive data are needed to further evaluate the potential impact of residual confounding on these associations.

In conclusion, we conducted a population-based cohort study in China to explore the association of GWG patterns with the risk of PTB and its subtypes. Excessive weight gain in underweight women, insufficient or excessive weight gain in women with normal pre-pregnancy BMI, and inadequate weight gain in overweight/obese women were all significantly associated with a higher risk of PTB. These findings underscore the importance of optimal GWG across all BMI categories to mitigate PTB risks, highlighting the need for tailored prenatal weight management strategies. Future research should validate these findings in prospective cohorts and diverse populations to confirm their generalizability. Such studies will also provide an opportunity to explore the mechanisms underlying the observed associations.

Methods

Study population and design

This retrospective cohort study was conducted in Wuhan, China, using electronic medical record data from a registry system, the Maternal and Children Healthcare Information Tracking System of Wuhan, which is an extensive integrated healthcare system including information on maternal demographic characteristics, medical history, antenatal examinations and delivery information from all the 93 hospitals and 121 community health centers in Wuhan. Eligible participants in this study were women who delivered a live singleton newborn with no congenital disabilities within 28–41 weeks' gestational age between March 1, 2011, to May 31, 2013 and lived in the urban area of Wuhan during pregnancy ($n = 106682$). Individuals with gestational age < 28 weeks were not included due to the small sample size ($n = 35$) and to ensure a consistent observation period for GWG between preterm and term births. Women younger than 16 years or older than 50 at delivery were excluded ($n = 6$). Also, participants with unknown height ($n = 547$), pre-pregnancy weight ($n = 23033$), or weight at 22–28 weeks of gestation ($n = 25958$) were excluded. A total of 57,138 women met the eligibility criteria and were included in the study. Among them, 55,414 had their weight measured at least once during the early pregnancy (8–20 weeks).

The Medical Ethics Committee of Wuhan Children's Hospital (Wuhan Maternal and Child Healthcare Hospital) approved the study and analysis plan (Approve Number: 2016003). All methods were carried out in accordance with relevant guidelines and regulations. Since this is a retrospective study based on registry system, the written informed consent was not applicable. The Medical Ethics Committee of Wuhan Children's Hospital (Wuhan Maternal and Child Healthcare Hospital) agreed to waive the need for written informed consent from all study participants.

Assessment of study variables

Gestational age was calculated from the delivery date and the date of the last menstrual period. Preterm delivery was defined as a delivery between 28 weeks, 0 days and 36 weeks, 6 days of gestation. Very preterm birth (< 28 weeks gestation) was not included in our study as there were few in this cohort (35 cases in the study time).

We additionally categorized the PTB subtype as either spontaneous PTB, PPROM, or medically indicated PTB based on the records of clinical diagnosis reported by the obstetrician at birth. Medically indicated PTB was defined by either induction or cesarean section without uterine contractions or rupture of membranes prior to delivery. PPROM was defined as the PTB with premature rupture of membranes (PROM), and spontaneous PTB was identified as early onset of delivery and no identifiable medical indication without a PROM diagnosis.

The gender of the infants was obtained from birth records. Pre-pregnancy weight and height were self-reported at the first antenatal care visit (usually during the first trimester). Pre-pregnancy BMI was calculated as weight (kg)/height (m^2 and then categorized into four groups based on recommendations by the Working Group On Obesity in China of the Chinese Ministry of Health (Underweight: <18.5 kg/m^2, normal weight: 18.5–23.9 kg/m^2, overweight: 24–27.9 kg/m^2, and obesity: ≥28 kg/m^2)[27].

The total GWG in the first and second trimesters was calculated by subtracting maternal pre-pregnancy weight from the weight before 28 weeks of gestation (if multiple measurements were available, the one closest to

Variables		PTB			Spontaneous PTB			PPROM			Medically indicated PTB		
		n (%)	Adjusted OR (95% CI)	*P*	*n* (%)	Adjusted OR (95% CI)	*P*	*n* (%)	Adjusted OR (95% CI)	*P*	*n* (%)	Adjusted OR (95% CI)	*P*
Total GWG in the first and second trimesters													
Underweight (< 18.5 kg/m^2)	Insufficient	31 (2.7)	1.27 (0.82–1.97)	0.281	12 (1.1)	1.51 (0.73–3.10)	0.263	5 (0.4)	0.72 (0.27–1.96)	0.523	14 (1.2)	1.47 (0.76–2.85)	0.258
	Adequate	61 (2.2)	1.00 (Reference)	-	20 (0.7)	1.00 (Reference)	-	17 (0.6)	1.00 (Reference)	-	24 (0.9)	1.00 (Reference)	-
	Excessive	306 (4.7)	2.19 (1.66–2.90)	< 0.001	97 (1.5)	2.18 (1.34–3.54)	0.002	86 (1.3)	2.17 (1.29–3.66)	0.004	123 (1.9)	2.12 (1.37–3.30)	0.001
Normal (18.5–23.9 kg/m^2)	Insufficient	157 (5.4)	2.09 (1.73–2.54)	< 0.001	46 (1.6)	1.98 (1.40–2.79)	< 0.001	39 (1.3)	1.66 (1.15–2.40)	0.007	72 (2.5)	2.43 (1.82–3.23)	< 0.001
	Adequate	374 (2.7)	1.00 (Reference)	-	113 (0.8)	1.00 (Reference)	-	114 (0.8)	1.00 (Reference)	-	147 (1.0)	1.00 (Reference)	-
	Excessive	955 (3.6)	1.35 (1.20–1.52)	< 0.001	265 (1.0)	1.25 (1.00-1.56)	0.048	271 (1.0)	1.24 (0.99–1.54)	0.059	419 (1.6)	1.49 (1.24–1.81)	< 0.001
Overweight/obesity (≥ 24 kg/m^2)	Insufficient	19 (8.3)	2.43 (1.32–4.48)	0.005	7 (3.1)	3.75 (1.23–11.43)	0.020	7 (3.1)	3.80 (1.25–11.49)	0.018	5 (2.2)	1.12 (0.40–3.14)	0.829
	Adequate	27 (3.9)	1.00 (Reference)	-	6 (0.9)	1.00 (Reference)	-	6 (0.9)	1.00 (Reference)	-	15 (2.1)	1.00 (Reference)	-
	Excessive	69 (3.1)	0.82 (0.52–1.29)	0.381	11 (0.5)	0.58 (0.21–1.58)	0.287	22 (1.0)	1.17 (0.47–2.90)	0.739	36 (1.6)	0.77 (0.42–1.42)	0.408
Average weekly eGWG (g/week)													
Underweight (< 18.5 kg/m^2)	Class I (< 100 g)	29 (2.6)	1.02 (0.68–1.52)	0.931	9 (0.8)	0.82 (0.41–1.66)	0.582	9 (0.8)	1.30 (0.63–2.69)	0.475	11 (1.0)	1.03 (0.54–1.97)	0.919
	Class II (100–399 g)	173 (2.6)	1.00 (Reference)	-	65 (1.0)	1.00 (Reference)	-	41 (0.6)	1.00 (Reference)	-	67 (1.0)	1.00 (Reference)	-
	Class III (≥ 400 g)	193 (8.2)	3.31 (2.68–4.09)	< 0.001	54 (2.3)	2.45 (1.70–3.53)	< 0.001	57 (2.4)	3.97 (2.65–5.95)	< 0.001	82 (3.5)	3.39 (1.44–4.70)	< 0.001
Normal (18.5–23.9 kg/m^2)	Class I (< 100 g)	313 (4.8)	1.84 (1.61–2.10)	< 0.001	97 (1.5)	1.80 (1.42–2.28)	< 0.001	87 (1.3)	1.86 (1.45–2.39)	< 0.001	129 (2.0)	1.78 (1.45–2.18)	< 0.001
	Class II (100–399 g)	794 (2.7)	1.00 (Reference)	-	242 (0.8)	1.00 (Reference)	-	213 (0.7)	1.00 (Reference)	-	339 (1.2)	1.00 (Reference)	-
	Class III (≥ 400 g)	337 (5.3)	1.99 (1.75–2.27)	< 0.001	76 (1.2)	1.47 (1.14–1.91)	0.004	109 (1.7)	2.34 (1.85–2.95)	< 0.001	152 (2.4)	2.05 (1.69–2.49)	< 0.001
Overweight/obesity (≥ 24 kg/m^2)	Class I (< 100 g)	37 (4.7)	1.30 (0.86–1.97)	0.208	10 (1.3)	1.94 (0.83–4.53)	0.127	12 (1.5)	1.44 (0.70–2.97)	0.320	15 (1.9)	1.00 (0.54–1.84)	0.990
	Class II (100–399 g)	68 (3.6)	1.00 (Reference)	-	12 (0.6)	1.00 (Reference)	-	20 (1.1)	1.00 (Reference)	-	36 (1.9)	1.00 (Reference)	-
	Class III (≥ 400 g)	10 (2.7)	0.75 (0.38–1.47)	0.394	2 (0.5)	0.86 (0.19–3.89)	0.848	3 (0.8)	0.73 (0.21–2.46)	0.605	5 (1.3)	0.73 (0.28–1.88)	0.516

Table 5. Associations of GWG patterns with PTB subtypes stratified by pre-pregnacy BMI in the adjusted model. Models were adjusted for maternal age at delivery, education level, parity, and offspring gender. *BMI* body mass index, *PTB* preterm birth, *GWG* gestational weight gain, *eGWG* early GWG, *OR* odds ratio, *CI* confidence interval.

BMI Category	Pre-pregancy BMI(kg/m^2)	Range of ecommended total Weight Gain (kg)	Range of weight gain in the 1st trimester (kg/week)	Recommended weekly weight gain in the 2nd and 3rd trimesters (kg/week)	Range of recommended total weight gain in the 1st and 2nd trimesters calculated according to Chinese standards (kg)
Underweight	<18.5	11.0–16.0	0–2.0	0.46 (0.37–0.56)	5.18–9.84
Normal weight	18.5–23.9	8.0–14.0	0–2.0	0.37 (0.26–0.48)	3.64–8.72
Overweight	24.0-27.9	7.0–11.0	0–2.0	0.30 (0.22–0.37)	3.08–7.18
Obesity	≥28.0	5.0–9.0	0–2.0	0.22 (0.15–0.30)	2.10–6.20

Table 6. Recommended gestational weight gain ranges for pregnant women with different pre-pregnancy BMI of Chinese standards[23].

28 weeks was selected). Subsequently, based on the Chinese guidelines (*Standard of Recommendation for Weight Gain during Pregnancy Period*)[23], total GWG in the first and second trimesters was classified as insufficient, adequate, or excessive according to the recommended ranges for the specific gestational week at which the actual weight measurement was taken. To provide a clearer understanding of the classification criteria used in this study, Table 6 shows the specific ranges for recommended GWG according to Chinese guideline[23]. A weight measurement taken between 8 and 20 weeks of gestation (if multiple measurements were available, the one closest to 20 weeks was selected) was used to evaluate eGWG that reported as a rate/week in grams. It was calculated by subtracting self-reported pre-pregnancy weight from measured weight during early gestation (8–20 weeks) and dividing by gestational week at measurement. It was categorized as class I (< 100 g/week), class II (100–399 g/week), and class III (≥ 400 g/week)[28].

Statistical analysis
Categorical variables were expressed as frequencies and percentages. Unconditional logistic regression was conducted to calculate odds ratios (ORs) and 95% confidence intervals (CIs) to evaluate the associations of total GWG in the first and second trimesters, and weekly eGWG with PTB subtypes. Models were adjusted for potential confounders, including maternal age at delivery, education level, gravidity, parity, and offspring gender. To assess effect modification, we included an interaction term between pre-pregnancy BMI and total GWG/eGWG in the logistic regression model. A significant (p value < 0.10) interaction term indicated heterogeneity across pre-pregnancy BMI categories. We further stratified the analysis by pre-pregnancy BMI and created separate logistic regression models for each stratum to evaluate the association within subgroups. All the statistical analyses were conducted with SAS, version 9.4 (SAS Institute, Inc., Cary, North Carolina), and p value < 0.05 was considered statistically significant.

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

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Author contributions
Yiyang Guo, Kai Chen, and Jin'e Zhang contributed equally to this work. Guo Yiyang and Kai Chen made substantial contributions to the conception and design of the study, data analysis, drafting of the manuscript. Jin'e Zhang made substantial contributions to the data analysis and revision of the manuscript. Chao Xiong and Aifen Zhou made substantial contributions to study design, intellectual direction, and revision of the manuscript. Yiming Zhang, Zhiguo Xia, Yuji Wang, Xiaoxuan Fan, Xiaofeng Mu, Luli Xu, and Menglan Guo made contributions to data collection and revision of the drafting of the manuscript. All authors were involved in drafting of the manuscript and approved the final manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

Ethics statement
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Additional information
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