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Research article

Effect modification of pre-pregnancy body mass index on association of gestational weight gain with birth weight

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A R T I C L E I N F O

Keywords:
Birth weight
Pre-pregnancy body mass index
Gestational weight gain
Small for gestational age
Large for gestational age

A B S T R A C T

Background: Maternal weight status, before or during pregnancy, is a significant determinant of fetus development, birth weight, and the short-term and long-term health outcomes of the offspring.
Objective: This study aimed to evaluate the effect modification of pre-pregnancy body mass index (BMI) on the associations of gestational weight gain (GWG) and birth weight, as per the latest guidelines from the Chinese Nutrition Society.
Methods: This is a retrospective cohort study performed in a tertiary hospital with the largest deliveries in Shanghai, China. This study included all women who had singleton live births from 2021 to 2022 (n = 50,391). Data on pre-pregnancy weight, GWG, and birth weight were extracted from the medical register system. Logistic regression models were used to estimate the associations of pre-pregnancy BMI and GWG with the risks of being small for gestational age (SGA) and large for gestational age (LGA). The potential for effect modification by BMI on the associations of GWG and birth weight was assessed using both additive and multiplicative scales.
Results: Pre-pregnancy BMI and GWG were consistently associated with birth weight. We observed a positive effect modification by underweight on the relationships between insufficient GWG and SGA both in multiplicative (adjusted odds ratio (OR), 2.49, 95 % confidence interval (CI): 2.06–2.99), and additive (relative excess risk due to interaction (RERI), 3.04, 95 % CI: 1.70–4.37) scales. Similarly, obesity was found to modify the effect of excessive GWG on the risk of LGA (adjusted OR, 3.82, 95 % CI, 3.14–4.63; RERI, 14.67, 95 % CI: 7.92–21.41).
Conclusion: Our findings indicate that increased GWG is associated with a higher risk of abnormal birth weight in singleton pregnancies. Additionally, there is evidence of an additive interaction between pre-pregnancy BMI and GWG on the risk of small for gestational age or large for gestational age.

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Key messages

What is already known on this topic- Maternal with abnormal weight contributed to the fetus development and birth weight. Furthermore, a series of studies have underscored the importance of ethnic-specific considerations when assessing the influence of maternal weight on birth outcomes, suggesting that standards for optimal BMI and GWG may vary across different ethnic groups.

What this study adds- There is an additive interaction between body mass index and gestational weight gain on the risk of small for gestational age or large for gestational age based on the latest Chinese Nutrition Society recommendations (CNS2021).

How this study might affect research, practice or policy-The study suggests that there is a critical need for women who are preparing for pregnancy or are already pregnant to achieve optimal weight and to maintain a gestational weight gain that aligns with the updated CNS2021 recommendations.

1. Introduction

In recent decades, there has been a significant increase in the prevalence of overweight or obesity during the perinatal period [1]. Maternal weight abnormalities, such as being underweight, overweight, and obesity, have been shown to impact fetus development, potentially affecting the short-term health outcomes (including birth weight, behavior, and neurodevelopment et al.) as well as long-term health outcomes (including cancer, childhood obesity et al.) [2–6]. Additionally, several studies have suggested a correlation between excessive gestational weight gain (GWG) and adverse behavior and neurodevelopment outcomes in offspring [7–11]. Therefore, it is necessary to investigate the associations between maternal body mass index (BMI), GWG and pregnancy outcomes, as both factors are routinely measured and can potentially be modifiable by behavioral interventions [12].

A series of studies have highlighted the importance of considering ethic-specific BMI categories and GWG recommendations [13–16]. Prior to 2021, most countries relied on the 2009 Institute of Medicine (IOM2009) guidelines for GWG [17], which were primarily based on data from USA dwelling community. However, some studies suggested that IOM2009 may not be suitable for Chinese pregnant women [18–20]. Consequently, based on data from the Chinese population, the Chinese Nutrition Society (CNS) published the standard announcement of GWG for pregnant women in 2021 (CNS2021) [21]. These standards differ from the IOM2009 guidelines in terms of recommended weight gain ranges (Table 1). However, since the publication of the CNS2021 recommendations, limited evidence exists regarding the associations between GWG and perinatal outcomes by different pre-pregnancy BMI categories.

Given that birth weight is an important indicator of intrauterine environment and maternal and newborn health, and is linked to various negative health outcomes, it is essential to evaluate the associations of BMI, GWG and birth weight. Although some evidence exists regarding this association, it often varies in terms of BMI categories. Furthermore, it remains unclear whether there is an effect modification between pre-pregnancy BMI and GWG, or if both factors independently influence birth weight. Therefore, our study aims to assess the associations between pre-pregnancy BMI, specific GWG and birth weight in singleton pregnancies, based on CNS2021 recommendations [21]. By employing interaction analysis, we hypothesize that there is an effect modification between pre-pregnancy BMI and GWG on birth weight.

2. Materials and methods

All women who delivered singleton live-born, with a gestational age of more than 28 weeks, at Shanghai First Maternity and Infant Hospital, China, between January 2021 and December 2022, were considered for inclusion in the study. Women were excluded if they had implausible weight (<35 kg) or height (<120 cm), or unrecorded pre-pregnancy weight, height, and gestational age. Finally, a total of 32,159 women were eligible for the analysis (Fig. 1).

2.1. Data collection

Demographics characteristics, including maternal age, insurance status, place of origin, weight before pregnancy and at delivery, height, family history of diabetes and hypertension were abstracted from the electronic health record. Medical history (including

Table 1
Comparison of BMI classification and recommendations on GWG between CNS2021 and IOM2009.

CNS2021		IOM2009	
BMI category (kg/m^2)	GWG recommendations of CNS2021 (kg)	WHO BMI category (kg/m^2)	GWG recommendations of IOM2009 (kg)
<18.5	11.0–16.0	<18.5	12.5–18.0
18.5–23.9	8.0–14.0	18.5–24.9	11.5–16.0
24–27.9	7.0–11.0	25–29.9	7.0–11.5
≥28	5.0–9.0	≥30	5.0–9.0

Abbreviations: BMI, body mass index; GWG, gestational weight gain; CNS, the Chinese Nutrition Society; IOM: the Institute of Medicine.

preexisting diabetes, hypertension, thyroid diseases, anemia, polycystic ovary syndrome (PCOS)), parity, gestational weeks, inpatient days, delivery mode, reproductive history, pregnancy complications (preeclampsia, hydramnios, oligohydramnios, gestational diabetes mellitus (GDM)), were obtained from discharge records. Additionally, newborn sex and birth weight were also recorded.

2.2. Exposures

The primary exposures were pre-pregnancy BMI and GWG. The pre-pregnancy BMI was calculated as pre-pregnancy weight (in kilograms) divided by squared height (in meters), and was classified into underweight, optimal weight, overweight, and obesity, following the recommendations of CNS2021 and WHO standards separately. GWG was defined as the difference between the pre-pregnancy weight and the weight at delivery, and it was classified as insufficient, appropriate, and excessive according to the CNS2021 and IOM2009 criteria separately (Table 1).

2.3. Outcomes of interest

The main outcome of interest was birth weight (grams), measured by neonatal nurses. The neonatal birth weight was referenced against a sex-specific, nationwide birth weight curve to delineate categories of small for gestational age (SGA) and large for gestational age (LGA) [22]. SGA was defined as a birth weight below the 10th percentile for gestational age, while LGA was defined as a birth weight above the 90th percentile. Infants whose birth weight fell between the 10th percentile and the 90th percentile were classified as appropriate for gestational age (AGA).

2.4. Statistical analysis

The statistical results of demographic characteristics were presented as numbers (percentage) or mean (standard deviation [SD]). Differences in characteristics were estimated by one-way analysis of variance (ANOVA) followed by F-test or non-parametric Mann–Whitney *U* test for continuous variables, and $\chi 2$ tests for categorical variables according the birth weight group. Univariate and multivariate logistic regression models were used to estimate the risks of SGA or LGA according to pre-pregnancy BMI and GWG. The optimal pre-pregnancy BMI or GWG within each criteria recommended listed in Table 1 was set as the reference for estimating the independent associations of pre-pregnancy BMI and GWG with birth weight. Potential confounders, selected according to prior to studies (GDM, preeclampsia, hydramnios, anemia (<110 g/L), and oligohydramnios) and biological basis (maternal age at conception, parity, delivery method), were adjusted in multivariable logistic regression models. We further adjusted for GWG or pre-pregnancy BMI when assessing the independent associations of pre-pregnancy BMI or GWG with birth weight.

We evaluated the interactive effect of pre-pregnancy BMI and GWG on the risks of SGA and LGA both in multiplicative and additive scales. The relative excess risk due to interaction (RERI), the attributable proportion due to interaction (AP), and the synergy index (SI) were calculated to estimate the additive interaction. The presence of an additive interaction was determined when the 95 % CI for RERI or AP did not include 0 or when the 95 % CI for SI did not contain 1 [23].

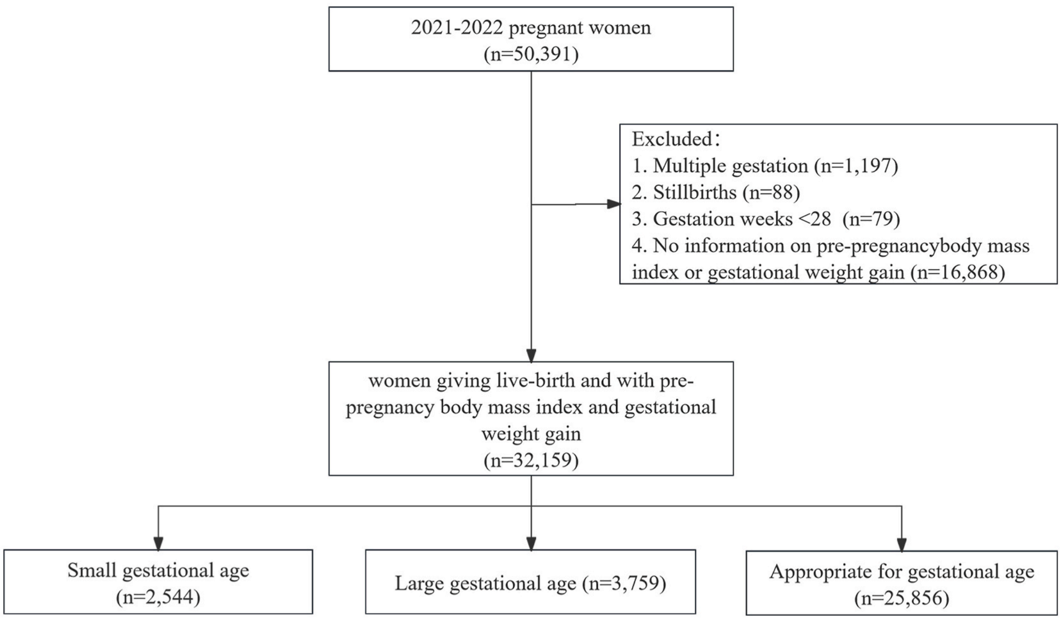

Fig. 1. Flow chart of the study population.

We also re-run all analyses based on IOM2009 recommendations to assess the associations between pre-pregnancy BMI, GWG and birth weight to assess the differences of the associations based on different criteria.

SAS version 9.4 statistical software packages (SAS Institute, Inc., Cary, NC, USA) and R Software v4.2.2 was used for statistical analyses. A two-sided P value less than 0.05 was considered statistically significant.

3. Results

Table 2 presented the basic characteristics of the study population. The mean age of the women at pregnancy was 31.49 (±3.82) years, with 19.71 % aged 35 years or older. Among the 32,159 women, 7,742 (24.07 %) were nulliparous, and 2,936 (9.13 %) conceived through in vitro fertilization (IVF). The mean pre-pregnancy BMI was 21.53 (±2.97) kg/m^2.

Table 3 showed the distribution of pre-pregnancy BMI and GWG classified by CNS2021 and WHO/IOM2009. There are 69.96 % classified as optimal weight, 14.37 % as overweight, and 3.33 % as obesity by CNS2021, while 76.16 % as optimal weight, 9.94 % as overweight, and 1.56 % as obesity by WHO. Additionally, 10.58 % women had insufficient GWG, 44.52 % had excessive GWG by CNS2021, while 29.67 % women had insufficient GWG, 28.66 % had excessive GWG by IOM2009.

Table 4 displayed the results of the univariate analysis examining the associations between maternal sociodemographic and clinical features with birth weight, categorized as SGA, LGA, and AGA based on defined criteria. The univariate regression analysis showed that maternal advanced age at pregnancy, gestational weeks, inpatient days, place of origin, method of pregnancy, parity, anemia, and diabetes history, were associated with birth weight ($P < 0.001$). Additionally, pregnancy complications, including preeclampsia, hydramnios, oligohydramnios, and GDM, were also associated with birth weight ($P < 0.001$). Furthermore, the risk of SGA was higher in girls than in boys (10.35 % vs. 5.65 %, $P < 0.001$).

Table 5 presented the independent relationships of pre-pregnancy BMI and GWG with birth weight. After adjusting for maternal age, parity, method of delivery, anemia, preeclampsia, GDM, hydramnios, and oligohydramnios, we observed that overweight and obesity were associated with an increased risk of LGA (overweight, OR, 1.67, 95 % CI: 1.53–1.82; obesity, OR, 2.29, 95 % CI: 1.97–2.66) and a decreased risk of SGA (overweight, OR, 0.76, 95 % CI: 0.66–0.87; obesity, OR, 0.61, 95 % CI: 0.45–0.82). Women with pre-pregnancy underweight had an increased risk of SGA (OR, 1.57, 95 % CI: 1.41–1.75) and a decreased risk of LGA (OR, 0.59, 95 % CI: 0.52–0.68), compared with women with optimal weight. Compared with women with GWG within CNS2021 recommendations, women with insufficient GWG had an increased risk of SGA (OR, 1.58, 95 % CI: 1.41–1.78) and a decreased risk of LGA (OR, 0.78, 95 % CI: 0.67–0.91), and vice versa. This association was slightly attenuated, but remained statistically significant after adjustment for GWG or pre-pregnancy BMI when assessing the independent associations of pre-pregnancy BMI or GWG on birth weight.

Table 6 presented the specific risks of SGA and LGA in each stratification according to both GWG and pre-pregnancy BMI and effect modification. The results indicated strong evidence of a positive effect modification by underweight on the relationships between insufficient GWG and SGA in multiplicative (OR, 2.49, 95 % CI: 2.06–2.99) scale. The additive interaction also indicated for underweight and insufficient GWG (RERI, 3.04, 95 % CI: 1.70–4.37; AP, 0.63, 95 % CI: 0.55–0.70; SI, 4.81, 95 % CI: 3.78–6.11). A positive RERI indicates a significant excess risk of SGA due to the combined effect of underweight and insufficient GWG over their individual

Table 2
Basic characteristics of the study population.

Characteristics	Mean (SD) or N (%)
Maternal age, mean (SD)	31.49 (3.82)
≥35 years (N (%))	6,337 (19.71)
Gestational weeks, mean (SD)	39.06 (1.37)
Inpatient days, mean (SD)	4.52 (3.13)
Newborn sex (boys), (N (%))	16,686 (51.89)
Birth weight (grams), mean (SD)	3,307.95 (437.7)
IVF (Yes) (N (%))	2,936 (9.13)
Parity (Nulliparous), N (%)	7,742 (24.07)
Place of origin (Non-Shanghai), N (%)	9,830 (30.57)
Insurance status (Self-pay), N (%)	28,810 (89.59)
Family history of diabetes, N (%)	756 (2.35)
Family history of hypertension, N (%)	3,319 (10.32)
Preexisting diabetes, N (%)	1,267 (3.94)
Hypertension, N (%)	914 (2.84)
Thyroid diseases, N (%)	4,222 (13.13)
Anemia, N (%)	2,999 (9.33)
PCOS, N (%)	234 (0.73)
Preeclampsia, N (%)	1,020 (3.17)
Hydramnios, N (%)	452 (1.41)
Oligohydramnios, N (%)	690 (2.15)
GDM, N (%)	3,185 (9.90)
Cesarean section, N (%)	16,827 (52.32)

Abbreviations: BMI: body mass index; IVF: in vitro fertilization; GDM: gestational diabetes; PCOS: polycystic ovary syndrome; N (%): numbers and percentages.

Table 3
Distribution of pre-pregnancy BMI and GWG classified by CNS2021 and WHO/IOM2009.

Categories	CNS2021 N (%)	WHO N (%)
Pre-pregnancy BMI		
Underweight	3,971 (12.35)	3,971 (12.35)
Optimal weight	22,497 (69.96)	24,491 (76.16)
Overweight	4,620 (14.37)	3,195 (9.94)
Obesity	1,071 (3.33)	502 (1.56)
Gestational weight gain	**CNS2021 N(%)**	**IOM2009 N(%)**
Insufficient	3,403 (10.58)	9,540 (29.67)
Excessive	14,318 (44.52)	9,216 (28.66)
Appropriate	14,438 (44.90)	13,403 (41.68)

Abbreviations: CNS: the Chinese Nutrition Society; IOM: the Institute of Medicine.

Table 4
Univariate analysis of maternal sociodemographic and clinical features with SGA and LGA.

Variables	SGA (n = 2,544)	LGA (n = 3,759)	AGA (n = 25,856)	P-value
Maternal age	31.12 (3.61)	32.08 (4.07)	31.44 (3.80)	<0.001
Gestational weeks	39.01 (1.64)	38.94 (1.30)	39.12 (1.35)	<0.001
Inpatient days	4.97 (4.21)	4.80 (3.53)	4.44 (2.93)	<0.001
Newborn sex				<0.001
Boys	943 (5.65)	2,456 (14.72)	13,287 (79.63)	
Girls	1,601 (10.35)	1,303 (8.42)	12,569 (81.23)	
IVF				<0.001
Yes	211 (7.19)	422 (14.37)	2,303 (78.44)	
No	2,333 (7.98)	3,337 (11.42)	23,553 (80.6)	
Parity				<0.001
Primipara	307 (3.97)	1,331 (17.19)	6,104 (78.84)	
Multipara	2,237 (9.16)	2,428 (9.94)	19,752 (80.89)	
Place of origin				<0.001
Non-shanghai	766 (7.79)	1,349 (13.72)	7,715 (78.48)	
Shanghai	1,778 (7.96)	2,410 (10.79)	18,141 (81.24)	
Insurance status				0.100
Self-pay	2,279 (7.91)	3,330 (11.56)	23,201 (80.53)	
Insurance	265 (7.91)	429 (12.81)	2,655 (79.28)	
Preexisting diabetes				<0.001
Yes	48 (6.35)	105 (13.89)	603 (79.76)	
No	2,496 (7.95)	3,654 (11.64)	25,253 (80.42)	
Anemia				<0.001
Yes	165 (5.5)	416 (13.87)	2,418 (80.63)	
No	2,379 (8.16)	3,343 (11.46)	23,438 (80.38)	
Delivery mode				<0.001
Cesarean section	1,170 (6.95)	2,641 (15.7)	13,016 (77.35)	
Vaginal delivery	1,374 (8.96)	1,118 (7.29)	12,840 (83.75)	
Preeclampsia				<0.001
Yes	189 (18.53)	106 (10.39)	725 (71.08)	
No	2,355 (7.56)	3,653 (11.73)	25,131 (80.71)	
Hydramnios				<0.001
Yes	6 (1.33)	106 (23.45)	340 (75.22)	
No	2,538 (8.00)	3,653 (11.52)	25,516 (80.47)	
Oligohydramnios				<0.001
Yes	142 (20.58)	27 (3.91)	521 (75.51)	
No	2,402 (7.63)	3,732 (11.86)	25,335 (80.51)	
GDM				<0.001
Yes	240 (7.54)	470 (14.76)	2,475 (77.71)	
No	2,304 (7.95)	3,289 (11.35)	23,381 (80.7)	

Abbreviations: IVF: in vitro fertilization; GDM: gestational diabetes; SGA: small for gestational age; LGA: large for gestational age; AGA: appropriate for gestational age; N (%): numbers and percentages.

effects, and the value of SI greater than 1 demonstrates a synergistic effect between underweight and insufficient GWG, where their combined effect on SGA risk is greater than the sum of their individual effect. The AP suggested that a proportion of 63 % SGA risk in women with both underweight and insufficient GWG can be attributed to the additive interaction of these two factors. We also observed an effect modification by obesity on the relationships between excessive GWG and LGA both in multiplicative scales (OR, 3.82, 95 % CI: 3.14–4.63) and in additive scales (RERI, 14.67, 95 % CI: 7.92–21.41; AP, 0.81, 95 % CI:0.77–0.86; SI, 7.16, 95 % CI: 5.78–8.87).

We re-run all the analysis by redefined GWG according to the IOM2009 recommendations. The results were present in sTable 1 and

Table 5
Associations of pre-pregnancy BMI, GWG with SGA and LGA.

	SGA				LGA			
	N (%)	OR (95%CI)	OR* (95%CI)	OR** (95%CI)	N (%)	OR (95%CI)	OR* (95%CI)	OR** (95%CI)
Pre-pregnancy BMI								
Underweight	491 (19.30)	1.59 (1.43–1.77)	1.57 (1.41–1.75)	1.39 (1.25–1.55)	234 (6.20)	0.55 (0.48–0.63)	0.59 (0.52–0.68)	0.67 (0.58–0.77)
Optimal weight	1,745 (68.60)	Ref (1.00)	Ref (1.00)	Ref (1.00)	2,406 (64.00)	Ref (1.00)	Ref (1.00)	Ref (1.00)
Overweight	259 (10.20)	0.78 (0.68–0.89)	0.76 (0.66–0.87)	0.79 (0.68–0.90)	857 (22.80)	1.87 (1.71–2.03)	1.67 (1.53–1.82)	1.53 (1.40–1.67)
Obesity	49 (1.90)	0.68 (0.51–0.91)	0.61 (0.45–0.82)	0.61 (0.45–0.82)	262 (7.00)	2.63 (2.27–3.04)	2.29 (1.97–2.66)	2.15 (1.84–2.50)
Gestational weight gain								
Insufficient	456 (17.90)	1.57 (1.40–1.76)	1.58 (1.41–1.78)	1.55 (1.38–1.75)	223 (5.90)	0.81 (0.70–0.94)	0.78 (0.67–0.91)	0.75 (0.64–0.87)
Excessive	811 (31.90)	0.68 (0.60–0.74)	0.65 (0.59–0.71)	0.68 (0.62–0.75)	2,328 (61.90)	2.06 (1.91–2.22)	2.05 (1.90–2.21)	1.88 (1.74–2.03)
Appropriate	1,277 (50.20)	Ref (1.00)	Ref (1.00)	Ref (1.00)	1,208 (32.10)	Ref (1.00)	Ref (1.00)	Ref (1.00)

Abbreviations: BMI: body mass index; SGA: small for gestational age; LGA: large for gestational age; N (%): numbers and percentages; OR: odds ratio; CI: confidence interval.
*Adjustment for maternal age, parity, method of delivery, anemia, preeclampsia, GDM, hydramnios, and oligohydramnios (model 2).
**Model 2+gestational weight gain or pre-pregnancy BMI.

Table 6
Effect modification of pre-pregnancy BMI on associations of GWG with birth weight.

Underweight	Insufficient GWG	SGA OR (95%CI)	Obesity	Excessive GWG	LGA OR (95%CI)
No	No	Ref (1.00)	No	No	Ref (1.00)
Yes	No	1.28 (1.10–1.49)	Yes	No	2.46 (1.82–3.34)
No	Yes	1.52 (1.30–1.77)	No	Yes	1.92 (1.75–2.10)
Yes	Yes	1.28 (0.98–1.68)	Yes	Yes	0.81 (0.57–1.16)
Multiplicative scales					
OR (95%CI)		2.49 (2.06–2.99)			3.82 (3.14–4.63)
Additive scales					
RERI (95%CI)		3.04 (1.70–4.37)			14.67 (7.92–21.41)
AP (95%CI)		0.63 (0.55–0.70)			0.81 (0.77–0.86)
SI (95%CI)		4.81 (3.78–6.11)			7.16 (5.78–8.87)

Abbreviations: GWG: gestational weight gain; SGA: small for gestational age; LGA: large for gestational age; OR: odds ratio; CI: confidence interval; RERI: relative excess risk due to interaction; AP: attribution proportion, SI: synergy index.

sTable 2 (supplementary file 1). Compared with optimal weight group, the odds of SGA in underweight group change from 1.39 (1.25–1.55) to 1.51 (1.35–1.68), while the odds of LGA in obesity group change from 2.15 (1.84–2.50) to 1.93 (1.55–2.39), and the confidence interval almost overlap. The estimates in other groups also did not change substantially when using the IOM2009 recommendations.

4. Discussion

The study aims to investigate the effect modification of pre-pregnancy BMI on the associations between GWG and birth weight, as well as to determine the independent relationships of BMI and GWG with birth weight. Our results suggest that both pre-pregnancy BMI and GWG are independent risk factors for the SGA or LGA, with evidence of effect modification by pre-pregnancy BMI on the associations of GWG with birth weight. Specifically, underweight women with insufficient GWG or obese women with excessive GWG may be likely to deliver SGA or LGA. In other words, women may have more benefit from achieving an optimal weight before pregnancy combined with maintaining appropriate GWG.

Our results on the independent associations of BMI and GWG with birth weight were consistent with previous studies conducted in several Asian areas [18,24–26] and western countries [27,28]. A meta-analysis published in 2017 also reported similar results [29]. However, it is worth noting the variation in categorization of BMI and GWG across studies. Additionally, birth weight assessment were also different among studies. For instance, the Danish study used birth weight lower than 3,000 g or heavier than 4,000 g as outcomes [28]. Jiang et al. performed a retrospective study among 8,209 mature singleton deliveries and suggested that IOM recommended GWG ranges may be excessive for the Chinese pregnant women across different BMI categories [19]. Furthermore, another study in Shanghai indicated a dose-response relationships between GWG and birth weight (correlation coefficient, $r = 0.56$), highlighting the significance of maintaining appropriate GWG during the third trimester to mitigate the likelihood of delivering infants with abnormal birth weight [30]. Consequently, when evaluating the associations between GWG and birth weight, it is imperative to consider the pattern of GWG alongside BMI categorization.

We observed differences between GWG recommendations in the CNS2021 and those in the IOM2009, with the former suggesting lower upper bounds by 0.5–2 kg across three BMI categories, while narrowing the recommended ranges by 0.5–1.5 kg. Nearly half of the women exceeded the CNS2021 recommendations of GWG thresholds, promoting the need for prospective cohort study to investigate the long-term health effect of GWG adherence to CNS2021 recommendations. In our study, we also compared the differences of the associations of pre-pregnancy BMI and GWG with birth weight between IOM2009 and CNS2021 recommendations, and the results were quite similar. We speculated that might be related to small proportion of obesity in Chinese women compared with those in western countries. In addition, a study from Japan indicated that IOM guidelines for GWG may lack external validity in Japanese women [15]. We also suggested that further studies regarding to obesity, especially extremely obesity (BMI $\geq$ 40 kg/m^2) should be conducted in Chinese pregnant women [31].

The evidence of effect modification by pre-pregnancy BMI on the GWG and birth weight was inconsistent. A study, including 1,164 women in Liuyang, a county in China, indicated that GWG during the first trimester was a determinant of birth weight [3], which partly supported our results. While weight instead of BMI, and weight gain within specific gestational intervals were used in this study, and was incomparable with total weight gain and BMI used in our study. The additional effect of GWG in women who were overweight or obesity before pregnancy was found to be marginal [32]. Because maternal weight and GWG are routinely measured and potentially modifiable by behavior intervention, our findings offer valuable insights for the early identification and intervention of high-risk pregnancies.

The study was conducted in a tertiary hospital with the largest delivery in the Yangtze River delta area of China, including Shanghai, Zhejiang, and Jiangsu. Statistic in the hospital showed that 75 % pregnant women were from these areas, with 68 % from Shanghai, and 5 % from Jiangsu and 2 % from Zhejiang. Hence, from a strictly scientific standpoint, our findings could be generalized to these areas at least. Nevertheless, this study also has some limitations that should be acknowledged. First, pre-pregnancy weight and height were self-reported at the first antenatal visit, and a recall bias would exist. However, a previous study, investigated associations of BMI and GDM, indicated that the effect size is likely to be underestimated when using self-report BMI [33]. Second, the lack of information on lifestyle behaviors, physical activities, and diet patterns et al. may result in residual confounding. Furthermore, although GWG was monitored at every antenatal visit, it was not registered in the medical system except for weight at the first visit and before delivery, limiting our ability to evaluate the effect of GWG pattern and GWG rate on birth weight as previous studies mentioned [30,34,35]. Future prospective studies are warranted to address these limitations.

5. Conclusion

In conclusion, our findings suggested that insufficient or excessive GWG by specific pre-pregnancy BMI categories was associated with an increased risk of SGA or LGA in singleton pregnancies. We recommended that women aiming for pregnancy or already pregnant should strive to achieve optimal weight or maintain appropriate GWG based on the updated CNS2021 recommendations.

Statement of ethics

The study was approved by the Ethics Committee of Shanghai First Maternity and Infant Hospital (no. KS23307). The written informed consent to participate in the study was obtained from participant.

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Data availability statement

Due to the privacy of participants, the study data cannot be available for public access. The original data are available on reasonable request from the corresponding author and the Ethics Committee of Shanghai First Maternity and Infant Hospital.

CRediT authorship contribution statement

Dan Hu: Writing – review & editing, Writing – original draft, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Zheying Zhou:** Writing – review & editing, Resources, Methodology, Investigation, Data curation. **Yingjie Ge:** Writing – review & editing, Resources, Investigation, Data curation. **Xiujuan Su:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Jing Tan:** Writing – review & editing, Validation, Supervision, Methodology, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e38478.

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