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RESEARCH

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Maternal pre-pregnancy body mass index and gestational weight gain on adverse birth outcomes in Chinese newborns: a retrospective study

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Abstract

Background Maternal and child health is an important measure of national well-being. This study further explored the individual and combined effects of maternal pre-pregnancy body mass index (BMI) and gestational weight gain (GWG) on adverse birth weight-related outcomes.

Methods A retrospective study was carried out at a maternal and child health hospital from 2018 to 2021, and a total of 17,506 eligible women were invited to participate. The associations of pre-pregnancy BMI and GWG with adverse birth outcomes were examined by using restricted cubic spline regression and binary logistic regression.

Results Pre-pregnancy BMI and GWG had non-linear associations with low birth weight and macrosomia. They were associated with an increased risk of macrosomia (Pre-pregnancy BMI for OR = 1.170, 95%CI:1.144 to 1.197, $P < 0.001$, and GWG for OR = 1.071, 95%CI:1.054 to 1.089, $P < 0.001$) and large for gestational age infant (LGA) (Pre-pregnancy BMI for OR = 1.125, 95%CI:1.111 to 1.141, $P < 0.001$, and GWG for OR = 1.045, 95%CI:1.036 to 1.054, $P < 0.001$). The high risk of low birth weight and preterm birth was observed among the group of women with inadequate GWG. The risks of macrosomia and LGA increased with pre-pregnancy BMI from low weight to overweight and obesity, and GWG from inadequate to overabundance, while small for gestational age infant was more prevalent in the low pre-pregnancy BMI group.

Conclusions Pre-pregnancy BMI and GWG exhibited non-linear associations with low birth weight and macrosomia. The various combinations of pre-pregnancy BMI and GWG had different effects on adverse birth weight-related outcomes.

Keywords Birth weight, Pre-pregnancy body mass index, Gestational weight gain, Adverse outcomes

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Introduction

Maternal and child health is an important measure of national well-being. Adverse birth outcomes including preterm birth, low birth weight, macrosomia, small (SGA) or large (LGA) for gestational age, and cesarean birth, have been associated with higher risks of short-term and long-term adverse health effects for children [1]. In China, the high prevalence of adverse birth outcomes was widely focused on the recent fertility policy transition [2]. For example, a recent study reported more than half of women suffer from adverse birth outcomes, especially for LGA and macrosomia [3]. In addition, the prevalence of obesity in women during pregnancy has been increasing worldwide in recent years, raising concerns due to its effect on adverse birth outcomes [4]. Obesity in pregnant women may be attributed to the interplay of pre-pregnancy weight status and gestational weight gain (GWG) [5, 6]. Addressing GWG as a preventable factor during pre-pregnancy care has been the primary option for preventing adverse birth outcomes [7, 8]. However, there is still a lack of effective weight management methods during pregnancy in China. It is crucial to comprehensively understand the relationships between maternal weight status and adverse birth outcomes in the Chinese population.

Many studies have confirmed that maternal pre-pregnancy body mass index (BMI) and GWG are both associated with risks of multiple adverse birth outcomes [9, 10]. The Institute of Medicine in America released guidelines on optimal GWG ranges based on a woman's pre-pregnancy BMI category to prevent adverse pregnancy outcomes. Improper GWG increases the risk of a baby being SGA or LGA for gestational age, caesarean birth, and preterm birth, while women with improper pre-pregnancy BMI are more likely to have improper GWG [5]. Furthermore, there may be non-linear relationships between maternal pre-pregnancy BMI and GWG with multiple adverse pregnancy outcomes. Saba et al. found a U-shaped association between preterm birth and GWG [11]. Despite the plethora of literature, few studies reported non-linear associations.

Additionally, numerous researchers have conducted studies on the interaction between maternal pre-pregnancy BMI and GWG about adverse pregnancy outcomes. However, most of the results indicated that no interaction effects were found, and the effect of maternal pre-pregnancy BMI on adverse outcomes is not attributed to its effect on GWG [12–14]. The pre-pregnancy BMI and GWG may be independent risk factors for adverse pregnancy outcomes. On the contrary, several previous studies reported the joint effects of maternal pre-pregnancy BMI and GWG on adverse pregnancy outcomes [15]. Investigating the combined impact of pre-pregnancy BMI and GWG could help prevent adverse pregnancy outcomes and offer precise weight management insights for women of reproductive age.

In this study, we analyzed data from a retrospective study conducted in central south China to evaluate the individual and combined effects of maternal pre-pregnancy BMI and GWG on adverse birth weight-related outcomes, and provide envidents to make more targeted and tailored strategies for preventing adverse birth outcomes in Chinese newborns.

Methods

Study population

A retrospective study was conducted at Changsha city maternal and child health hospital from 2018 to 2021, located in Changsha, the provincial capital of Hunan Province, a megacity in central South China. Inclusion criteria: pregnant women with gestational age over 20 weeks, 18 years or older, delivering in the hospital, and live births. A total of 17,506 eligible women were invited to participate. Of those, 550 pregnant women due to gestational weeks of the first visit in 13 weeks and above, 1033 pregnant women due to missing pre-pregnancy weight, height, or delivery weight were excluded. The final sample size was 15,923.

Pre-pregnancy BMI and gestational weight gain

The pre-pregnancy weight was defined as the weight status within 1 month before pregnancy. Pre-pregnancy weight and height were measured by health doctors using a height and weight device during the first pre-pregnancy care visit, expressed in kg and cm. Pre-pregnancy BMI was calculated as weight (kg) divided by the square of height (m). Pregnant women were categorized as underweight (BMI lower than 18.5 kg/m^2), normal weight (BMI 18.5 to 23.9 kg/m^2), overweight (BMI 24 to 27.9 kg/m^2), and obese (BMI over 28 kg/m^2 and above) groups according to the Working Group on Obesity in China [16]. As only a small number of women were obese, overweight and obese women were combined.

The GWG was defined as the difference between maternal weight at delivery and pre-pregnancy weight. GWG was calculated by subtracting pre-pregnancy weight from maternal weight at delivery. Maternal weight at delivery was recorded by midwifery before delivery, expressed in kg. GWG was categorized into inadequate, adequate, and overabundance based on the Institute of Medicine GWG Guidelines 2009 in America [17].

Birth weight-related adverse outcomes

The study focused on several adverse outcomes, including low birth weight, macrosomia, SGA, LGA, and preterm birth. Information on perinatal birth weight and gestational age was obtained from the medical birth registry, which was developed by the local hospital and recorded by nurses or obstetricians. Low birth weight was defined as a birth weight below 2500 g, while macrosomia was defined as a birth weight over 4000 g. Preterm birth was indicated by a gestational age at birth of less than 37 weeks. SGA was the birth weight below the 10th percentile of the average weight among infants of the same gestational age. LGA was the birth weight above the 90th percentile of the average weight among infants of the same gestational age. SGA and LGA were determined based on growth standard curves of birth weight, length and head circumference of Chinese newborns of different gestation [18].

Covariates

The demography variables, including maternal age (below 25 years, 25 to 29 years, 30 to 34 years, 35 to 39 years, and 40 years and above), residence (city or rural), occupation (farming or migrant workers, public officials, enterprise personnel, businessmen, unemployed, or other), education (junior and below, high/technical secondary school, or college and above), gravidity (once, twice, three times, or four times and above), and parity (once, twice, or three times and above) were also retrieved from the medical birth registry.

Statistical analysis

Continuous variables were described using mean and standard deviation (SD) for normally distributed data, while categorical variables were described using frequency and percentage. To compare demographic and sociological characteristics among birth weight-related adverse outcomes, Chi-Square Tests were used.

The potential non-linear relationships between pre-pregnancy BMI and GWG with birth weight and its related adverse outcomes were analyzed using restricted cubic spline regression. Data were both adjusted for maternal age, residence, occupation, education, gravidity, and parity. Additionally, the mediating effect model of pre-pregnancy BMI, GWG, and birth weight was established using AMOS 23.0 software.

Furthermore, binary logistic regression analysis models were used to calculate the odds ratio (OR) and 95% confidence interval (CI) of birth weight-related adverse outcomes associated with pregnancy BMI and GWG. The final model adjusted for maternal age, residence, occupation, education, gravidity, and parity. Besides, to better understand the effect of GWG on the relationship between pre-pregnancy BMI and adverse birth weight outcomes, the interactions of pre-pregnancy BMI and GWG on birth weight-related adverse outcomes were analyzed using binary logistic regression models.

To evaluate the combined effects, the participants were divided into nine groups based on their pre-pregnancy BMI (low weight, normal weight, and overweight and obesity) and GWG (inadequate, adequate, and overabundance). Within these groups, OR was calculated for adverse outcomes, comparing them to individuals with pre-pregnancy normal weight and adequate GWG.

The restricted cubic spline regression analysis was performed using R software, version 4.2.2, provided by the R Project for Statistical Computing. The other statistical analysis was conducted by SPSS software (version 13.0, Chicago, IL, USA). The P value less than 0.05 was considered statistically significant.

Results

Population characteristics

Table 1 showed the characteristics of the participants according to birth weight-related adverse outcomes. A total of 15,923 pregnant women were included in the analyses. The prevalence of low birth weight, macrosomia, SGA, LGA, and preterm birth were 4.03, 5.19, 2.76, 24.91, and 5.23%, respectively. There was an increasing trend for low birth weight, LGA, and preterm birth with maternal age. The pregnant women in the city had a lower prevalence of low birth weight and preterm birth than in rural. The pregnant women with higher gravidity suffered from higher LGA, but lower SGA. The pregnant women with higher parity suffered from higher low birth weight and preterm birth (Table 1).

Association of pre-pregnancy BMI and GWG with birth weight

A non-linear and positive association between the pre-pregnancy BMI and birth weight was found (for non-linearity, $P<0.001$; for overall, $P<0.001$; Fig. 1A). However, a non-linear and positive association between the GWG and birth weight was found (for non-linearity, $P=0.010$; for overall, $P<0.001$; Fig. 1B). Moreover, the result the mediating effect model of GWG on pre-pregnancy BMI and birth weight indicated that an indirect association of pre-pregnancy BMI with birth weight by GWG was found. The effect value was −5.63 (95%CI: -6.53 to -4.91) (Fig. 1C).

Association of pre-pregnancy BMI and GWG with birth weight-related adverse outcomes

The non-linear associations between the pre-pregnancy BMI and risk of low birth weight (for non-linearity, $P=0.001$; Fig. 2A), macrosomia (for non-linearity, $P<0.001$; Fig. 2B), SGA(for non-linearity, $P<0.001$; Fig. 2C), and LGA(for non-linearity, $P<0.001$; Fig. 2D) were found. Table 2 showed the association of pre-pregnancy BMI with birth weight-related adverse outcomes by logistic regression analysis. After adjusting for potential confounders, pre-pregnancy BMI increased the risk of macrosomia (OR=1.170, 95%CI:1.144 to 1.197, $P<0.001$), LGA (OR=1.125, 95%CI:1.111 to 1.141,

Table 1 Demographic and sociological characteristics related to birth weight-related adverse outcomes in central South China

Characteristics	Total (*n*)	Low birth weight (*n* (%))		Macrosomia (*n* (%))		SGA (*n* (%))		LGA (*n* (%))		Preterm birth (*n* (%))	
Maternal age											
Below 25 years	809	25	(3.09)**	34	(4.20)*	29	(3.58)	156	(19.28)**	29	(3.58)**
25 to 29 years	5654	184	(3.25)	263	(4.65)	162	(2.87)	1278	(22.60)	243	(4.30)
30 to 34 years	6821	289	(4.24)	388	(5.69)	173	(2.54)	1784	(26.15)	359	(5.26)
35 to 39 years	2290	124	(5.41)	130	(5.68)	67	(2.93)	631	(27.55)	174	(7.60)
40 years and above	349	19	(5.44)	11	(3.15)	9	(2.58)	117	(33.52)	27	(7.74)
Residence											
City	11,553	427	(3.70)*	617	(5.34)	316	(2.74)	2889	(25.01)	560	(4.85)**
Rural	4370	214	(4.90)	209	(4.78)	124	(2.84)	1077	(24.65)	272	(6.22)
Ocuppation											
Farming or migrant workers	1171	64	(5.47)*	55	(4.70)	49	(4.18)	281	(24.00)**	75	(6.40)
Public officials	2831	99	(3.50)	139	(4.91)	75	(2.65)	664	(23.45)	130	(4.59)
Enterprises personnel	3148	107	(3.40)	161	(5.11)	78	(2.48)	728	(23.13)	157	(4.99)
Businessmen	1045	42	(4.02)	57	(5.45)	29	(2.78)	306	(29.28)	57	(5.45)
Unemployed	2166	92	(4.25)	109	(5.03)	55	(2.54)	559	(25.81)	119	(5.49)
Others	5562	237	(4.26)	305	(5.48)	154	(2.77)	1428	(25.67)	294	(5.29)
Education											
College and above	12,367	462	(3.74)*	651	(5.26)	340	(2.75)	3035	(24.54)	615	(4.97)
High/technical secondary school	2491	126	(5.06)	128	(5.14)	72	(2.89)	646	(25.93)	150	(6.02)
Junior and below	881	45	(5.11)	39	(4.43)	24	(2.72)	233	(26.45)	57	(6.47)
Unkown	184	8	(4.35)	8	(4.35)	4	(2.17)	52	(28.26)	10	(5.43)
Gravidity											
Once	5951	273	(4.59)*	262	(4.40)*	218	(3.66)**	1131	(19.01)**	317	(5.33)**
Twice	4906	153	(3.12)	265	(5.40)	108	(2.20)	1272	(25.93)	212	(4.32)
Three times	2829	111	(3.92)	173	(6.12)	74	(2.62)	837	(29.59)	145	(5.13)
Four times and above	2237	104	(4.65)	126	(5.63)	40	(1.79)	726	(32.45)	158	(7.06)
Parity											
Once	8289	227	(2.74)**	421	(5.08)	271	(3.27)**	1735	(20.93)**	300	(3.62)**
Tiwice	7229	352	(4.87)	390	(5.39)	155	(2.14)	2117	(29.28)	460	(6.36)
Three times and above	405	62	(15.31)	15	(3.70)	14	(3.46)	114	(28.15)	72	(17.78)
Total	15,923	641(4.03)		826(5.19)		440(2.76)		3966(24.91)		832(5.23)	

* $P<0.05$;* $P<0.001$; comparing by Chi-Square Tests; SGA: Small for gestational age; LGA: Large for gestational age

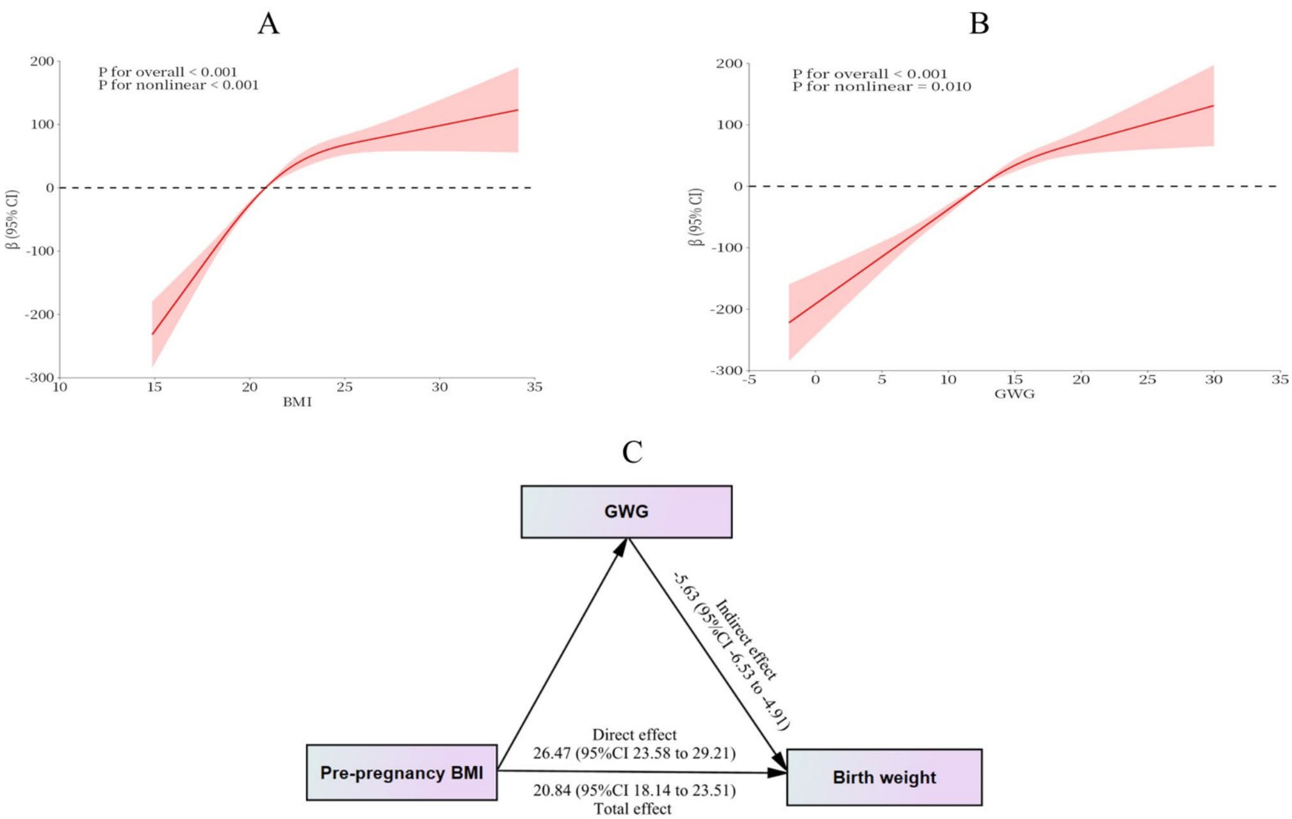

Fig. 1 The association of pre-pregnancy BMI and GWG with birth weight. (**A**) Non-linear associations of pre-pregnancy BMI (kg/m^2) with birth weight by the restricted cubic spline regression. (**B**) Non-linear associations of GWG (kg) with birth weight by the restricted cubic spline regression. Data were both adjusted for maternal age, residence, occupation, education, gravidity, and parity. (**C**) The mediating effect model of pre-pregnancy BMI, GWG, and birth weight

$P<0.001$) and preterm birth (OR=1.035, 95%CI:1.009 to 1.062, $P=0.008$), while decreased the risk of SGA (OR=0.886, 95%CI:0.851 to 0.923, $P<0.001$).

The non-linear associations between the GWG and risk of low birth weight (for non-linearity, $P=0.001$; Fig. 3A), macrosomia(for non-linearity, $P<0.001$; Fig. 3B), and preterm birth (for non-linearity, $P<0.001$; Fig. 3E) were found. Furthermore, GWG was associated with increased risk of macrosomia (OR=1.071, 95%CI:1.054 to 1.089, $P<0.001$) and LGA (OR=1.045, 95%CI:1.036 to 1.054, $P<0.001$), while is associated with lower risk of low birth weight (OR=0.920, 95%CI:0.903 to 0.939, $P<0.001$), SGA (OR=0.967, 95%CI:0.945 to 0.989, $P=0.004$), and preterm birth (OR=0.910, 95%CI:0.895 to 0.926, $P<0.001$) after adjusting for potential confounders by logistic regression analysis (Table 2).

Besides, GWG was more weakly associated with macrosomia, SGA, and LGA than maternal pre-pregnancy BMI. Subsequently, no significant interaction was found between pre-pregnancy BMI and GWG on birth weight-related adverse outcomes ($P_{interaction}>0.05$, Table 2).

Combination effects analyses of pre-pregnancy BMI and GWG with birth weight-related adverse outcomes.

In Table 3, the joint causal effect of pre-pregnancy BMI and GWG on birth weight-related adverse outcomes was examined. Compared to the reference groups of pre-pregnancy BMI with normal weight and GWG with adequate, the study found a high OR for low birth weight in the groups of pre-pregnancy BMI with low weight and GWG with inadequate (OR=2.594, 95%CI:1.824 to 3.688), and pre-pregnancy BMI with overweight and obesity and GWG with inadequate (OR=2.743, 95%CI:1.758 to 4.280). Similar result was found for preterm birth, with a high OR in the groups of pre-pregnancy BMI with low weight and GWG with inadequate (OR=2.123, 95%CI:1.537 to 2.934), and pre-pregnancy BMI with overweight and obesity and GWG with inadequate (OR=2.525, 95%CI:1.701 to 3.748).

The highest OR for macrosomia and LGA were observed in the group with pre-pregnancy BMI categorized as overweight and obese and GWG categorized as overabundant (for macrosomia, OR=2.951, 95%CI:2.357 to 3.694; for LGA, OR=1.908, 95%CI:1.656 to 2.199). On the other hand, the lowest OR was found in the group with pre-pregnancy BMI categorized as low weight and GWG categorized as inadequate (for macrosomia,

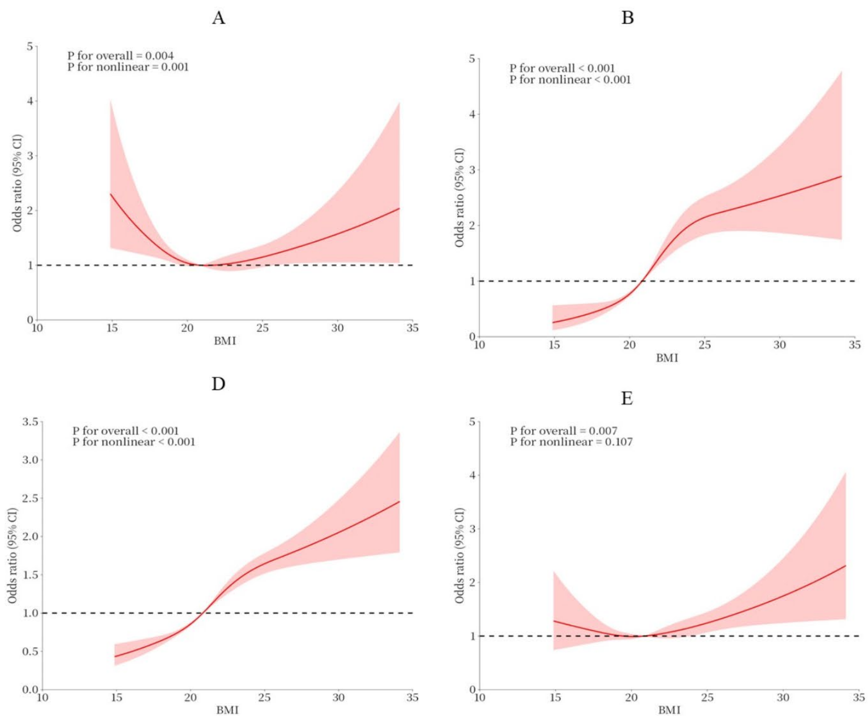

Fig. 2 Non-linear associations of pre-pregnancy BMI with adverse pregnancy outcomes by the restricted cubic spline regression. (**A**) Low birth weight; (**B**) Macrosomia; (**C**) SGA; (**D**) LGA; (**E**) Preterm birth. Data were adjusted for maternal age, residence, occupation, education, gravidity, and parity

Table 2 The association of pre-pregnancy BMI and GWG with birth weight-related adverse outcomes by logistic regression analysis

Adverse outcome	Pre-pregnancy BMI		GWG		$P_{interaction}$
	OR(95%CI)	*P*	OR(95%CI)	*P*	
Low birth weight	0.995 (0.965, 1.025)	0.726	0.920 (0.903, 0.939)	< 0.001	0.183
Macrosomia	1.170 (1.144, 1.197)	< 0.001	1.071 (1.054, 1.089)	< 0.001	0.764
SGA	0.886 (0.851, 0.923)	< 0.001	0.967 (0.945, 0.989)	0.004	0.230
LGA	1.125 (1.111, 1.141)	< 0.001	1.045 (1.036, 1.054)	< 0.001	0.192
Preterm birth	1.035 (1.009,1.062)	0.008	0.910 (0.895, 0.926)	< 0.001	0.888

Data were adjusted for maternal age, residence, occupation, education, gravidity, and parity. BMI: body mass index; GWG: gestational weight gain; SGA: Small for gestational age; LGA: Large for gestational age; OR: odds ratios; CI: confidence interval

OR=0.202, 95%CI:0.095 to 0.431; for LGA, OR=0.389, 95%CI: 0.304 to 0.497).

The high OR for SGA was found in the group with pre-pregnancy BMI categorized as low weight and GWG categorized as inadequate (OR=2.196, 95%CI:1.511 to 3.191), and pre-pregnancy BMI categorized as low weight and GWG categorized as adequate (OR=2.109, 95%CI:1.498 to 2.970).

Discussion

In this retrospective study, we explored the independent and combination effects of pre-pregnancy BMI and GWG on birth weight-related adverse outcomes among newborns in south-central China. Our findings revealed that pre-pregnancy BMI was associated with an increased risk of macrosomia, LGA, and preterm birth, but a decreased risk of SGA. On the other hand, GWG was linked to a higher risk of macrosomia and LGA, but a lower risk of low birth weight, SGA, and preterm birth. Furthermore, both pre-pregnancy BMI and GWG exhibited non-linear associations with low birth weight and macrosomia. When analyzing the combined effects, it was observed that inadequate GWG was associated with a higher risk of low birth weight and preterm birth. The greatest risk of macrosomia and LGA was seen in the group with pre-pregnancy BMI categorized as overweight or obese, along with excessive GWG, while the lowest OR was found in the group with low pre-pregnancy BMI and inadequate GWG.

In this study, pre-pregnancy BMI is associated with the risk of several birth weight-related adverse outcomes. A higher BMI preconception increased the risk of high birth weight-related outcomes including macrosomia, LGA, and preterm birth, while decreased risk of low birth weight-related outcomes SGA. These results were consistent with many previous studies [19]. The reason

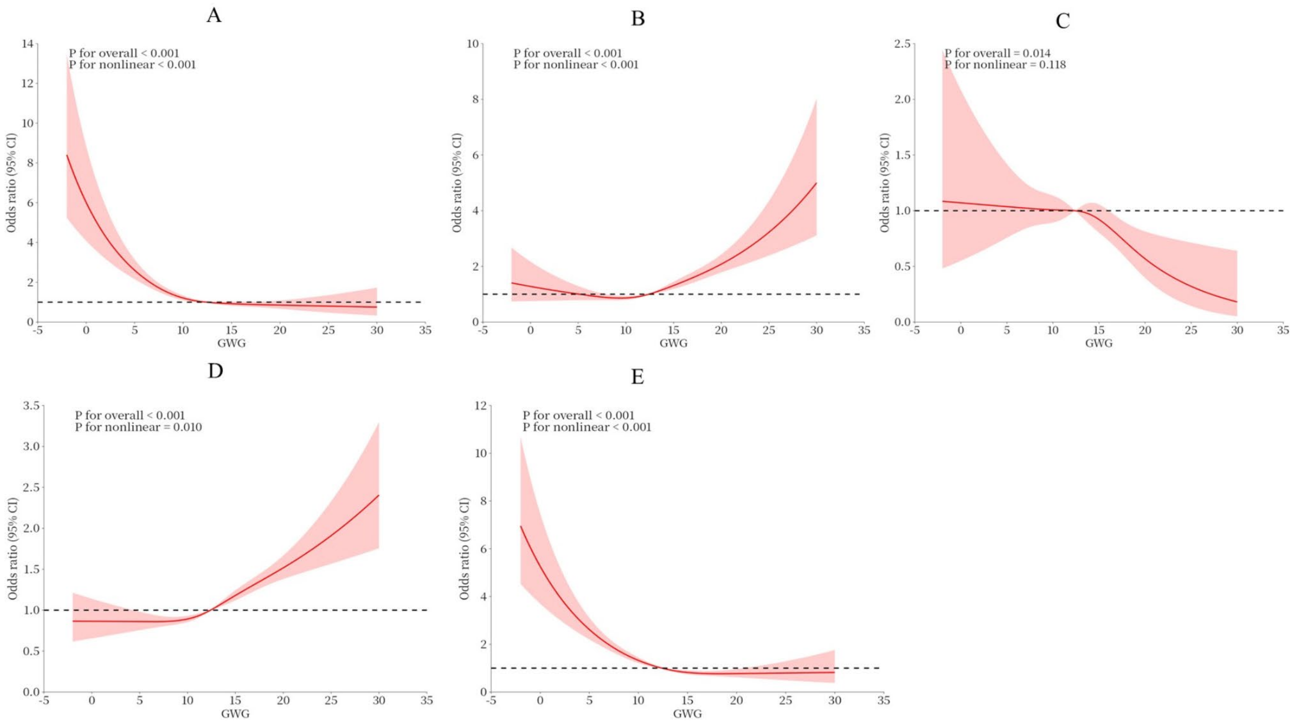

Fig. 3 Non-linear associations of GWG with adverse pregnancy outcomes by the restricted cubic spline regression. (**A**) Low birth weight; (**B**) Macrosomia; (**C**) SGA; (D) LGA; (**E**) Preterm birth. Data were adjusted for maternal age, residence, occupation, education, gravidity, and parity

Table 3 The joint causal effect of pre-pregnancy BMI and GWG with birth weight-related adverse outcomes by logistic regression analysis

Group	Low birth weight	Macrosomia	SGA	LGA	Preterm birth
	OR(95%CI)	OR(95%CI)	OR(95%CI)	OR(95%CI)	OR(95%CI)
Normal weight + Adequate	Reference	Reference	Reference	Reference	Reference
Low weight + Inadequate	2.594(1.824,3.688)**	0.202(0.095,0.431) **	2.196(1.511,3.191) **	0.389(0.304,0.497) **	2.123(1.537,2.934) **
Low weight + Adequate	1.421(0.967,2.090)	0.283(0.161,0.498) **	2.109(1.498,2.970) **	0.614(0.510,0.740) **	1.022(0.703,1.485)
Low weight + Overabundance	1.697(0.912,3.158)	1.328(0.775,2.278)	1.038(0.452,2.384)	1.003(0.744,1.354)	1.035(0.537,1.997)
Normal weight + Inadequate	1.758 (1.417, 2.182)**	0.684 (0.556, 0.842)**	1.243 (0.972,1.589)	0.727(0.660, 0.802) **	1.796 (1.493,2.159) **
Normal weight + Overabundance	0.963(0.713,1.302)	1.718(1.401,2.107) **	0.757(0.528,1.085)	1.344(1.201,1.505) **	0.726(0.545,0.967) *
Overweight and obesity + Inadequate	2.743(1.758,4.280)**	1.643(1.069,2.523) *	0.756(0.330,1.731)	1.247(0.977,1.592)	2.525(1.701,3.748) **
Overweight and obesity + Adequate	1.579(1.123,2.220)*	1.557(1.185,2.046) *	0.786(0.482,1.281)	1.355(1.167,1.573) **	1.722(1.294,2.291) **
Overweight and obesity + Overabundance	1.263(0.887,1.798)	2.951(2.357,3.694) **	0.791(0.491,1.276)	1.908(1.656,2.199) **	1.360(1.008,1.836) *

* $P<0.05$; ** $P<0.001$. SGA: Small for gestational age; LGA: Large for gestational age; OR: odds ratios; CI: confidence interval

may be attributed to maternal abnormal glucose metabolism. Many studies have confirmed gestational diabetes mellitus is a known risk factor for high birth weight [20], and pre-pregnancy BMI has a close association with gestational diabetes mellitus [21]. The pathophysiology was that maternal hyperglycemia leads to fetal hyperinsulinemia and increased utilization of glucose, and thus increased fetal adipose tissue [22].

Furthermore, our findings are broadly consistent with previous studies that had explored associations of GWG with birth weight, showing an increased risk of macrosomia and LGA [20], but decreased risk of low birth weight, SGA, and preterm birth [23]. The reason can be clarified by the same reason of pre-pregnancy BMI. Many studies reported that GWG also was associated with gestational diabetes mellitus [24]. In addition, several studies reported that pre-pregnancy BMI was more strongly associated with adverse birth outcomes than the GWG [25, 26]. Therefore, there was a dispute about the predictive value of GWG on the adverse pregnancy outcomes assessed. Similar results were found in the associations for macrosomia, SGA, and LGA in this study. Nevertheless, we also found inconsistent results that GWG is associated with a lower risk of low birth weight and preterm birth, but no similar associations were found on pre-pregnancy BMI. GWG reflects the biological energy supply between mother and fetus. Adequate GWG replaced adequate nutrition supply during pregancy decreased the risk of low birth weight and preterm birth [27]. These results suggested that GWG plays an important role in several birth weight-related adverse outcomes.

Unconsistenting with previous studies using conventional BMI or GWG categories [23, 25, 26], we examined the non-linear or linear relationship using pre-pregnancy BMI and GWG as continuous variables by the restricted cubic spline regression analysis. Few studies have examined the non-linear relationship of pre-pregnancy BMI and GWG with birth weight-related adverse outcomes [28]. One used the restricted cubic spline regression analysis to examine the association with preterm birth and found the risk of preterm birth increased with both low and high pre-pregnancy BMI [29]. In our study, similar non-linear association was found on GWG with preterm birth. Besides, our results also showed that pre-pregnancy BMI and GWG both had nonlinear associations with the risk of low birth weight and macrosomia. Results of the restricted cubic spline regression analysis provided additional insight regarding dose-response relations [30], which may provide evidence for making precise intervention strategies for preventing birth weight-related adverse outcomes.

Previous studies reported that gestational weight gain has a differential effect on adverse birth weight outcomes between women of different pre-pregnancy body mass index categories [15]. A similar result was found in our study. Compared to the reference group, low birth weight and preterm birth risk were found higher for women whose GWG was inadequate. This suggested that GWG with inadequate was the primary reason for low birth weight and preterm birth. However, several studies considered the very limited impact of interventions for pregnancy outcomes during pregnancy on GWG due to the weaker association in recent years [31–33]. Subsequently, the risks of macrosomia and LGA were increased with pre-pregnancy BMI from low weight to overweight and obesity, and GWG from inadequate to overabundance. This suggested that macrosomia and LGA were influenced by the synergistic effect of pre-pregnancy BMI and GWG. In addition, the higher risks of SGA were only found in women with low weight, which hinted that maternal pre-pregnancy low weight was the main impact factor of SGA.

In addition, we further explored the mechanism of combination effects. Our analyses found no interaction but a moderation effect of GWG on the association of pre-pregnancy BMI with birth weight. Previous studies reported that higher pre-pregnancy BMI has been associated with lower GWG [25, 34], which was consistent with our result that GWG masked the effect of BMI. These results provided more targeted and tailored preventive strategies for birth adverse outcomes.

A strength of our study is that we have used pre-pregnancy BMI and GWG as a continuum to examine non-linear associations and have been able to explore associations with birth weight-related adverse outcomes, which provided additional insight regarding dose-response relations. Moreover, identifying individuals at high risk based on the combined assessment of pre-pregnancy BMI and GWG enables more targeted and tailored preventive strategies. This study is limited because we only used data from one maternal and child hospital, which could lead to biased effect estimates. Additionally, while we considered detailed information about many potential sociodemographic factors associated with mothers, we did not include other confounding factors related to the weight status of the mothers and the birth outcomes, such as iron deficiency anaemia, digestive system disease, and drug use affecting maternal weight. This limitation may restrict the generalization of our results.

Conclusion

We found that pre-pregnancy BMI and GWG were associated with birth weight and its related adverse outcomes. Pre-pregnancy BMI and GWG both exhibited non-linear associations with low birth weight and macrosomia. However, the various combinations of pre-pregnancy BMI and GWG had different effects on birth weight-related outcomes. Inadequate GWG was found to be the primary reason for low birth weight and preterm birth. Additionally, macrosomia and LGA were influenced by the synergistic effect of pre-pregnancy BMI and GWG. Maternal pre-pregnancy low weight was the main factor for SGA. Gestational weight gain mediated the association of pre-pregnancy BMI with birth weight by masking the effect. Our findings have highlighted a more detailed perspective on the intertwining of these factors and their influence on adverse birth weight outcomes, providing crucial implications for clinical practice and public health strategies.

Abbreviations

GWG	gestational weight gain
BMI	body mass index
SGA	Small for gestational age
LGA	Large for gestational age

SD standard deviation
OR odds ratios
CI confidence interval

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Author contributions
Z.H. and A.Z. performed the literature search, analyzed and interpreted the data, and drafted the manuscript. X.T. andJ.W. collected, verified, and interpreted the data. A.Z. contributed to the design of this study and data interpretation. All authors reviewed and approved the final version of the manuscript.

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Data availability
The datasets generated and/or analysed during the current study are not publicly available due information privacy but are available from the corresponding author on reasonable request.

Declarations

Ethical statement
The study was approved by the Ethics Committee of the Changsha City Maternal and Child Health Care Hospital (No. EC-20230111-04). The data from a retrospective study are de-identified, and the requirement for informed consent was therefore waived.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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