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Improving dietary energy and antioxidative property benefit early maternal BMI and further manage adverse pregnancy outcomes with better weight gain†

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Hang-Yu Li, Bing-Jie Ding,* Jia Wang, Xin-Li Yang, Zhi-Wen Ge, Nan Wang, Ya-Ru Li, Yan-Xia Bi, Cong-Cong Wang, Zheng-Li Shi, Yu-Xia Wang, Yi-Si Wang, Cheng Li, Ze-Bin Peng and Zhong-Xin Hong*

Dietary characteristics affect maternal status in early pregnancy, which is important for later outcomes. Yet, Chinese dietary guidelines for pregnant women are not specific to obesity, overweight, and underweight. Moreover, because the whole pregnancy process has a long period, an intermediate bridge to connect early maternal BMI and pregnancy outcomes is needed. In this cohort with 1785 Chinese pregnant women from 2020 to 2022, the 37.98% of participants had abnormal BMI in early pregnancy. Less energy from carbohydrates (<50%) but more from protein (>20%) and fat (>30%) led to excessive energy intake, which was a risk factor for maternal obesity (adjusted OR (AOR): 1.49, 95%CI: 1.02-2.17) and overweight (AOR: 1.47, 95%CI: 1.00-2.18). Furthermore, the risk of maternal underweight was increased by the poor antioxidative diet (AOR: 2.80, 95%CI: 1.02-7.66) with 20.28% lower intake of isoflavones and the imbalanced dietary structure (AOR: 3.95, 95%CI: 1.42-10.95) with less energy from fat (<20%) and unsaturated fatty acids (<3%). Following the timeline of gestation to delivery, early maternal obesity, overweight, and underweight increased the risk of abnormal body weight gain during pregnancy (AOR: 1.91-3.62, 95%CI: 1.20-6.12). Subsequently, the abnormal weight gain further provoked adverse pregnancy events, like gestational diabetes mellitus, hypertensive disorders, cesarean section, and macrosomia (AOR, 1.33-2.58; 95%CI, 1.04-4.17). To minimize these threats, more energy from carbohydrates (>65%) while less energy from protein (<10%) and fat (<20%) were recommended for obese/overweight pregnant women in China. Meanwhile, underweight pregnant women were recommended to increase the intake of dietary antioxidants (especially isoflavones) with more energy from fat (>30%) and unsaturated fatty acids (>11%). Finally, gestational body weight gain, as the potential intermediate bridge, should be paid more attention.

Introduction

Maternal status in early pregnancy is important to the long-term life quality of pregnant women and neonates.[1] Because the increase in total body water during pregnancy makes body mass index (BMI) less reliable[2], maternal BMI in the early stage (around the 8-week gestation) attracts more concern.[3] In terms of maternal and neonatal health, previous literature usually paid more attention to the obese population[4-6], which separately correlated maternal obesity/overweight to limited adverse outcomes (like hypertension, colorectal cancer, and gut dysbiosis).[6-8] However, underweight still be a concern in developing areas.[9] China is one of the largest developing countries in the world, which is undergoing economic structural transformation, so in this recent cohort from 2020 to 2022 in Beijing, China, we not only focused on pregnant ladies with large sizes but also cared about lean ones.

Facing the health threats triggered by abnormal maternal BMI, optimizing dietary structure could be a promising practical strategy[10,11], yet inconsistent results were reported. Several studies showed that low-glycemic index food with more protein intake might benefit lean mass, weight gain, and pregnancy complications in obese and overweight women.[12,13] Whereas other literature reported that protein balance was not related to gestational body weight gain and neonate adiposity[14], while serum long-chain polyunsaturated fatty acid might link to gestational diabetes mellitus.[15] For Chinese citizens, the most authoritative and responsible standards to improve their intake of food, energy, and nutrients are the Dietary Guidelines for Chinese Residents and the Dietary Reference Intakes for China.[16-19] However, the current recommendations for Chinese pregnant women are general, which do not make targeted suggestions for maternal obesity, overweight, and underweight, respectively[18]. We would like to describe maternal dietary characteristics classified by different BMI status, and hopefully, provide several insights for refining Chinese dietary guidelines for pregnant women. Furthermore, previous inconsistent studies mainly focused on the amount of food consumption[12-15], we hypothesize that energy contribution from different macronutrients could be more

Department of Clinical Nutrition, Beijing Friendship Hospital, Capital Medical University, Beijing, China
** Corresponding authors: Zhong-Xin Hong (E-mail: hongzhongxin@vip.sina.com), Bing-Jie Ding (E-mail: bingjieding@ccmu.edu.cn)*
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crucial. Meanwhile, whether other dietary characteristics (like antioxidative property) play a role in the process from early maternal BMI to later pregnancy outcomes is worth exploring.

Because the whole pregnancy process has a long period, identifying an anchor point to connect early maternal BMI and later pregnancy outcomes is valuable for clinical practice. Previous evidence implied that gestational body weight gain could be the promising intermediate bridge.[20] The most of studies on gestational body weight gain were according to the recommendations from the American National Academy of Medicine (formerly known as the Institute of Medicine) since 2009.[20-23] However, the recommendations for Americans might not be the best choices for Chinese.[24] In 2021, the localized guidelines for gestational body weight gain in China were released[25], which provided us a great opportunity to more reasonably explored the importance of body weight gain during pregnancy among Chinese women. Moreover, previous literature had paid more attention to the relationship between the amount of weight gain and adverse pregnancy events.[26, 27] For example, the excessive amount of body weight gain increased the risk of preeclampsia, while the inadequate amount of that increased the risk of small for gestational age infant in the United States.[22] In this study, we would like to comprehensively consider both the total amount of body weight gain before parturition and the average rate of body weight gain per week based on real-world data from China.

In short, the present study assessed early maternal BMI-related dietary characteristics, and targeted dietary recommendations were proposed for Chinese pregnant ladies with obesity, overweight, and underweight, respectively. Also, the role of gestational body weight gain as an intermediate bridge to connect abnormal maternal BMI in early gestation and multiple adverse pregnancy events was clarified. Hopefully, our findings could have some significance in managing chronic disease among the Chinese pregnant population.

Materials and methods

Study design, setting, and participants

The present cohort study was conducted at two different campuses of the Beijing Friendship Hospital located in the Xicheng and Tongzhou districts from October 2020 to August 2022, and 1785 participants were included. All procedures were supervised and approved by the Ethics Committee in the Beijing Friendship Hospital, Capital Medical University (No. 2021-P2-128-01), and the Strengthening Reporting of Observational Studies in Epidemiology (STROBE) was followed. The first prenatal visit with gestational file registration around the 8-week gestation was the baseline, and follow-up was processed with subsequent prenatal visits, until completing parturition as the endpoint. Inclusion criteria: (1) age>18, (2) passed the first prenatal examination, (3) finished dietary survey in nutrition clinic. Exclusion criteria: (1) low quality of dietary survey (truncated and incomplete data), (2) multiple pregnancy, (3) not delivering in the investigator hospital, (4) low-quality data, (5) unfortunate stillbirth.

Exposures and outcomes

Maternal BMI in early pregnancy was the exposure factor (based on self-reported height and weight measurement at baseline). Adverse pregnancy events were outcomes, including three major categories[28]: (1) pregnancy complications and comorbidities, such as gestational diabetes mellitus, hypertensive disorders of pregnancy, morning sickness, and thyroid disease; (2) abnormal delivery and its complications, such as delivery mode (cesarean section or natural vaginal delivery), birth injury, fetal distress, the premature rupture of fetal membranes, postpartum hemorrhage, and preterm birth; (3) fetal and neonatal abnormalities, such as meconium-stained amniotic fluid, macrosomia, and low birth weight. More details were presented in Supplementary Information†.

Gestational body weight gain assessment

Both the total amount and weekly rate of gestational body weight gain were analyzed. The total amount of weight gain was equal to predelivery weight minus baseline weight. The weekly rate of weight gain was equal to the amount of weight gain divided by gestational weeks. According to the Chinese Nutrition Society guidelines of gestational body weight gain[24, 25], for maternal underweight (BMI<18.5), normal (18.5≤BMI<24), overweight (24≤BMI<28), and obesity (BMI≥28), the optimal amount of weight gain were 11-16 kg, 8-14 kg, 7-11 kg, and 5-9 kg, respectively, and the optimal rate of weight gain were 0.46 (0.37-0.56)kg/week, 0.37 (0.26-0.48) kg/week, 0.30 (0.22-0.37) kg/week, and 0.22 (0.15-0.30) kg/week, respectively.

Demographic characteristics and biochemical indexes

Maternal age, gestational registration week (first prenatal visit), delivery week, parity, education level, physical activity, working status/income, smoking and drinking status were collected and used to address potential bias. Regular blood biochemical indexes were abstracted from medical records.

Dietary survey and calculation of energy and nutrient intake

Based on the Dietary Guidelines for Chinese Residents[18] and our previous work[29], a food-frequency questionnaire was used, which contained 67 subtypes of foods involving grains, vegetables, fruits, animal foods, dairy, legumes, nuts, and others. A dietary survey was conducted at gestational registration (first prenatal visit) by nutritionists. Dietary survey data were transformed into the amount of food consumption per day after quality assessment. According to the China Food Composition Database[30] and the Dietary Reference Intakes for China[19], dietary energy and nutrient intake were calculated.

Overall dietary characteristics assessment

Pregnant woman-based multidimensional dietary indexes and conceptions were selected to assess dietary status, including dietary quality, antioxidative property, dietary guideline adherence, eating habits, consistency of Dietary Approaches to Stop Hypertension Diet (DASH) principle, anti-inflammatory potential, and dietary diversity. Calculation details of all dietary

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indexes were presented in Supplementary Methods†. Only dietary quality and antioxidative property showed significant differences in proportion among maternal BMI groups.

Dietary quality was reflected by the Chinese Diet Balance Index for Pregnancy (DBI-P) accompanied with Diet Quality Distance (DQD), High Bound Score (HBS), and Low Bound Score (LBS).[31] A lower score of DBI-P with DQD, HBS, and LBS meant better dietary quality. The DBI-P with DQD represented the conditions of an imbalanced diet, which were classified into 4 degrees: high level (>56 points), middle level (39-56 points), low level (20-38 points), and almost no problem (1-19 points). The DBI-P with HBS represented the conditions of excessive dietary intake, which were classified into 5 degrees: high level (>32 points), middle level (23-32 points), low level (12-22 points), and almost no problem (1-11 points), and no excessive intake (0 points). The DBI-P with LBS represented the conditions of inadequate dietary intake, which were classified into 5 degrees: high level (>44 points), middle level (31-44 points), low level (16-30 points), and almost no problem (1-15 points), and no excessive intake (0 points). The proportion of dietary quality status among maternal BMI groups was studied and described.

Dietary antioxidative property was reflected by the Dietary Antioxidant Quality Score (DAQS).[32] A higher score of DAQS meant a better antioxidative property. The status of dietary antioxidative property were classified into 4 degrees: very poor quality (0 points), low quality (1-2 points), average quality (3-4 points), and high quality (5-6 points). The proportion of dietary antioxidative property among maternal BMI groups was studied.

Statistical analysis

Based on SPSS software (version 26.0, IBM, USA), measurement data were described as median [interquartile (IQR)] due to the lack of distribution normality, and categorical data were described as count (n) and proportion (%). Subsequently, the Kruskal-Wallis test and Chi-square test were used to analyze the differences between maternal BMI groups. The unadjusted odds ratio (UOR) and adjusted OR (AOR) were measured by logistic regression, with demographic characteristics (age, gestational registration week, delivery week, parity, education level, physical activities, working status/income, smoking status, and drinking status) and diabetes mellitus history as covariates. Neonatal delivery mode was extra adjusted when abnormal delivery and its complications as well as fetal and neonatal abnormalities were analyzed.[33-36] Correlation coefficient (r) was analyzed by Spearman correlation. The *P* value <0.05 was deemed as a significant difference.

Results

The basic information of pregnant women with abnormal BMI in early pregnancy

A total of 1785 pregnant women with a median (IQR) age of 31 (29-34) years were involved, and the flowchart was presented in Fig. 1. The median (IQR) weeks of gestational registration and neonatal delivery were 8 (7-9) and 39 (38-40). The majority of participants were primipara, had college and bachelor education, did not regularly exercise, still working every day, nonsmoking, and nondrinking (Table 1).

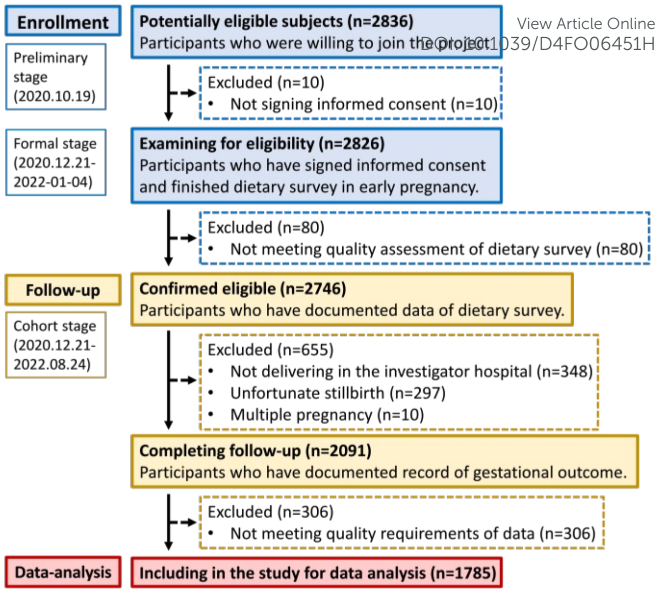

Fig. 1 The flowchart for the cohort of pregnant women in Beijing.

The proportion of obesity, overweight, underweight, and normal pregnant women was 7.51%, 22.07%, 8.40%, and 62.02%, respectively. Meanwhile, their median (IQR) BMI were 30.5 (29.1-31.8), 25.3 (24.5-26.4), 17.7 (17.3-18.3), and 21.1 (19.9-22.3), respectively. Next, the median (IQR) of predelivery weights among obesity, overweight, underweight, and normal groups were 88.25 (83.53-96.00) kg, 78.00 (74.00-83.13) kg, 61.00 (57.53-64.00) kg, and 68.00 (64.00-73.00) kg, respectively. Furthermore, early maternal BMI was positively correlated to predelivery weight (r=0.751, P<0.001). Additionally, maternal obesity/overweight had hyperlipidemia with higher levels of glycated hemoglobin, fasting blood glucose, thyroid stimulating hormone, free T3, and creatinine than normal pregnant women. Whereas maternal underweight showed the opposite trends of serum lipids with lower levels of fasting blood glucose and creatinine (Table 2).

In short, 37.98% of pregnant women had abnormal BMI in early pregnancy with lipid and glucose metabolic disorders, and the positive correlation between early BMI and predelivery weight implied gestational body weight gain was important.

Characteristics of dietary quality, antioxidative property, food consumption, and energy intake among maternal BMI groups

Based on dietary quality assessment via the DBI-P index, obesity group had a higher proportion of "low level of imbalanced diet" than normal group (71.64% vs 60.79%, *P*<0.05). Overweight group had a higher proportion of "moderate level of excessive diet" (6.85% vs 4.16%, *P*<0.05) (Table 3). Underweight group had a higher proportion of "high level of imbalanced diet" (5.33% vs 1.90%, *P*<0.05) and "high level of inadequate dietary intake" (10.00% vs 4.25%, *P*<0.05) than normal group (Table 3). Moreover, the DAQS index suggested that underweight group had more women with "very poor dietary antioxidative quality" than normal group (6.00% vs 1.81%, *P*<0.05) (Table 3). No difference had been found in dietary guideline adherence, eating habits, consistency of DASH principle, anti-inflammatory potential, and dietary diversity (Table S1†).

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Table 1 The basic characteristics of the pregnant woman

Basic characteristics	Total (n=1785)	Normal (n=1107)	Underweight (n=150)	Overweight (n=394)	Obesity (n=134)	*P* value
Age (year)	31 (29-34)	31 (29-34)	30 (28-32)	32 (30-35)	33 (30-35)	<0.001
Gestational registration (week)	8 (7-9)	8 (7-9)	8 (79)	8 (7-9)	8 (7-9)	0.062
Delivery week	39 (38-40)	39 (39-40)	39 (39-40)	39 (38-40)	39 (38-40)	0.001
Parity (n, %)						
Never	1291 (72.32%)	793 (71.64%)	123 (82.00%)	285 (72.34%)	90 (67.16%)	0.12
One time	471 (26.39%)	299 (27.01%)	27 (18.00%)	103 (26.14%)	42 (31.35%)	
Two times	23 (1.29%)	15 (1.35%)	0 (0%)	6 (1.52%)	2 (1.49%)	
total	1785 (100%)	1107 (100%)	150 (100%)	394 (100%)	134 (100%)	
Education level (n, %)						
Master degree or above	382 (21.4%)	279 (25.2%)	26 (17.33%)	66 (16.75%)	11 (8.21%)	<0.001
College and bachelor	1165 (65.27%)	695 (62.78%)	101 (67.33%)	265 (67.26%)	104 (77.61%)	
High school or less	106 (5.94%)	57 (5.15%)	10 (6.67%)	27 (6.85%)	12 (8.96%)	
Unwilling to inform	132 (7.39%)	76 (6.87%)	13 (8.67%)	36 (9.14%)	7 (5.22%)	
total	1785 (100%)	1107 (100%)	150 (100%)	394 (100%)	134 (100%)	
Physical activities (n, %)						
Regular exercise						
Yes	285 (15.97%)	183 (16.53%)	18 (12.00%)	57 (14.47%)	27 (20.15%)	0.219
No	1500 (84.03%)	924 (83.47%)	132 (88.00%)	337 (85.53%)	107 (79.85%)	
total	1785 (100%)	1107 (100%)	150 (100%)	394 (100%)	134 (100%)	
Walking steps per day						
Over 6000 steps	637 (35.69%)	389 (35.14%)	43 (28.67%)	149 (37.82%)	56 (41.79%)	0.283
3000~6000 steps	532 (29.8%)	338 (30.53%)	45 (30.00%)	112 (28.43%)	37 (27.61%)	
Less 3000 steps	616 (34.51%)	380 (34.33%)	62 (41.33%)	133 (33.75%)	41 (30.6%)	
total	1785 (100%)	1107 (100%)	150 (100%)	394 (100%)	134 (100%)	
Working status/income (n, %)						
Not working (<$10511 per year)	310 (17.37%)	179 (16.17%)	27 (18.00%)	76 (19.29%)	28 (20.9%)	0.344
Working (≥$10511 per year)	1475 (82.63%)	928 (83.83%)	123 (82.00%)	318 (80.71%)	106 (79.1%)	
total	1785 (100%)	1107 (100%)	150 (100%)	394 (100%)	134 (100%)	
Smoking status (n, %)						
Smoking	31 (1.74%)	21 (1.90%)	1 (0.67%)	5 (1.27%)	4 (2.99%)	0.407
Nonsmoking	1754 (98.26%)	1086 (98.10%)	149 (99.33%)	389 (98.73%)	130 (97.01%)	
total	1785 (100%)	1107 (100%)	150 (100%)	394 (100%)	134 (100%)	
Drinking status (n, %)						
Drinking	199 (11.15%)	121 (10.93%)	16 (10.67%)	52 (13.2%)	10 (7.46%)	0.308
Nondrinking	1586 (88.85%)	986 (89.07%)	134 (89.33%)	342 (86.8%)	124 (92.54%)	
total	1785 (100%)	1107 (100%)	150 (100%)	394 (100%)	134 (100%)	

Data were presented as median (IQR) or counts with proportion (%).

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Table 2 The difference of biochemical indexes among BMI groups

Biochemical indexes	Normal [as control]	Obesity	*P* value	Overweight	*P* value	Underweight	*P* value
Lipid metabolism							
TG (mmol/L)	0.99 (0.78-1.31)	1.36 (1.04-1.78)	<0.001	1.17 (0.89-1.46)	<0.001	0.93 (0.76-1.11)	0.001
TC (mmol/L)	4.36 (3.93-4.88)	4.68 (4.21-5.44)	0.01	4.57 (4.05-5.05)	<0.001	4.21 (3.88-4.73)	0.008
HDL-C (mmol/L)	1.54 (1.35-1.73)	1.39 (1.19-1.56)	<0.001	1.40 (1.26-1.60)	<0.001	1.58 (1.43-1.77)	0.006
LDL-C (mmol/L)	2.23 (1.97-2.53)	2.61 (2.22-3.04)	<0.001	2.41 (2.04-2.79)	<0.001	2.04 (1.88-2.43)	<0.001
Glucose metabolism							
At the time of gestational file registration (first prenatal visit)							
Glycated hemoglobin (%)	5.00 (4.80-5.20)	5.20 (5.00-5.50)	<0.001	5.10 (4.80-5.30)	<0.001	5.00 (4.80-5.20)	0.323
Fasting blood glucose (mmol/L)	4.65 (4.44-4.87)	4.94 (4.67-5.36)	<0.001	4.77 (4.51-5.05)	<0.001	4.56 (4.39-4.84)	0.005
At the time of diabetes mellitus screening (within the second trimester)							
Fasting blood glucose (mmol/L)	4.39 (4.14-4.68)	4.75 (4.32-5.03)	<0.001	4.55 (4.30-4.95)	<0.001	4.39 (4.15-4.59)	0.041
One-hour blood glucose (mmol/L)	7.62 (6.48-8.74)	8.68 (7.02-9.92)	<0.001	8.27 (7.07-9.32)	<0.001	7.59 (6.55-8.65)	0.174
Two-hour blood glucose (mmol/L)	6.72 (5.92-7.72)	7.30 (6.14-9.10)	<0.001	7.16 (6.34-8.19)	<0.001	6.66 (5.50-7.34)	0.018
OGTT area (mmol/Lh)	13.11 (11.81-14.75)	14.61 (12.49-16.58)	<0.001	14.12 (12.49-15.64)	<0.001	12.65 (11.41-14.42)	0.082
Thyroid and other metabolic indexes							
TSH (μIU/mL)	1.11 (0.55-1.87)	1.45 (0.94-2.21)	<0.001	1.34 (0.72-2.02)	0.061	0.97 (0.33-1.56)	0.098
free T3 (pg/mL)	3.13 (2.88-3.38)	3.29 (2.97-3.52)	0.005	3.21 (2.98-3.49)	0.031	3.15 (2.89-3.48)	0.913
free T4 (ng/dL)	0.88 (0.80-0.98)	0.81 (0.74-0.91)	0.155	0.84 (0.79-0.95)	0.025	0.94 (0.83-1.04)	0.074
Creatinine (μmol/L)	49.40 (45.90-53.60)	53.00 (49.00-57.18)	<0.001	50.40 (45.80-54.80)	0.005	48.00 (44.70-51.10)	0.002

Data were presented as median (IQR). Abbreviations: TG, triglyceride; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; OGTT, oral glucose tolerance test; TSH, thyroid stimulating hormone.

For daily food intake, obesity and overweight groups consumed more animal and plant proteins from unprocessed red meat and other sources. Underweight group consumed less carbohydrate and plant protein from legumes as well as less animal protein from eggs (Table S2†).

In the details of macronutrients and energy intake, obesity group consumed a higher amount of protein (115.88 vs 103.41 g/day, *P*=0.011), fat (70.22 vs 61.12 g/day, P=0.035), and total energy (2026.32 vs 1837.59 kcal/day, *P*=0.014) than normal group. After analyzing the structure of macronutrient-provided energy, obesity group absorbed more energy derived from protein (463.51 vs 414.63 kcal/day, *P*=0.011) than normal group (Table 4). Similarly, overweight group showed an excessive trend of protein intake (107.13 vs 103.41 g/day, *P*=0.051) and excessive energy from protein (428.37 vs 414.63 kcal/day, *P*=0.051) (Table 4). Besides, underweight group consumed a lower amount of lipids contrasting to normal group, such as cholesterol (413.5 vs 508.74 mg/day, *P*=0.001), saturated fatty acid (10.28 vs 12.57 g/day, *P*=0.018), and polyunsaturated fatty acid (5.73 vs 6.59 g/day, *P*=0.048). Moreover, underweight group had a trend to absorb less energy derived from protein (360.95 vs 414.63 kcal/day, *P*=0.065) (Table 4).

For micronutrients, underweight group showed a significant 20.28% lower intake of isoflavones than normal group (1.14 vs 1.43 mg/day, *P*=0.012) (Table 4). In fact, all 3 major subtypes of isoflavones showed a decreased intake in underweight group, including daidzein (1.50 vs 2.05 mg/day, *P*=0.006), glycitein (0.34 vs 0.42, *P*=0.016), and genistein (1.51 vs 1.95 mg/day, *P*=0.016) (Table 4). However, overall intake of vitamins, minerals, and other food components (like dietary fiber, flavonoids, and anthocyanidins) was adequate among obesity, overweight, and underweight groups (Table S3†).

In short, early abnormal BMI came with an imbalanced diet. Obesity and overweight groups had excessive dietary intake with more energy from protein, so maternal obese and overweight might need to control energy intake derived from protein. Besides, underweight group had a high-level of imbalanced diet with inadequate dietary intake (like lipids and isoflavones) and less energy from protein. Combining the prevalence of "very poor dietary antioxidative quality" in underweight group in this study, and the widely known fact that isoflavones possessed significant antioxidative property[37,38], isoflavones intake should be paid more attention in maternal underweight in China.

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Table 3 The proportion of overall dietary status among BMI groups

Overall dietary quality assessment	Normal [as control]	Obesity	*P* value	Overweight	*P* value	Underweight	*P* value
DAQS (n, %)							
Very poor quality	20 (1.81%)	4 (2.99%)	>0.05	9 (2.28%)	>0.05	9 (6.00%)	<0.05
Low quality	58 (5.24%)	2 (1.49%)	>0.05	14 (3.55%)	>0.05	7 (4.67%)	>0.05
Average quality	84 (7.59%)	6 (4.48%)	>0.05	30 (7.61%)	>0.05	12 (8.00%)	>0.05
High quality	945 (85.36%)	122 (91.04%)	>0.05	341 (86.56%)	>0.05	122 (81.33%)	>0.05
total	1107 (100%)	134 (100%)	>0.05	394 (100%)	>0.05	150 (100%)	>0.05
DQD of DBI-P (n, %)							
High level of an imbalanced diet (very poor dietary intake)	21 (1.90%)	1 (0.75%)	>0.05	4 (1.02%)	>0.05	8 (5.33%)	<0.05
Moderate level of an imbalanced diet (poor dietary intake)	263 (23.76%)	22 (16.42%)	>0.05	99 (25.13%)	>0.05	43 (28.67%)	>0.05
Low level of an imbalanced diet (imbalanced dietary intake)	673 (60.79%)	96 (71.64%)	>0.05	252 (63.96%)	>0.05	86 (57.33%)	>0.05
Almost no problem (good dietary intake)	150 (13.55%)	15 (11.19%)	>0.05	39 (9.89%)	>0.05	13 (8.67%)	>0.05
total	1107 (100%)	134 (100%)	>0.05	394 (100%)	>0.05	150 (100%)	>0.05
HBS of DBI-P (n, %)							
High level of excessive intake	5 (0.45%)	2 (1.49%)	>0.05	0 (0.00%)	>0.05	1 (0.67%)	>0.05
Moderate level of excessive intake	46 (4.16%)	4 (2.99%)	>0.05	27 (6.85%)	<0.05	7 (4.67%)	>0.05
Low level of excessive intake	282 (25.47%)	31 (23.13%)	>0.05	112 (28.43%)	>0.05	34 (22.67%)	>0.05
Almost no excessive intake	771 (69.65%)	97 (72.39%)	>0.05	253 (64.21%)	<0.05	108 (71.99%)	>0.05
No excessive intake	3 (0.27%)	0 (0.00%)	>0.05	2 (0.51%)	>0.05	0 (0.00%)	>0.05
total	1107 (100%)	134 (100%)	>0.05	394 (100%)	>0.05	150 (100%)	>0.05
LBS of DBI-P (n, %)							
High level of inadequate intake	47 (4.25%)	4 (2.99%)	>0.05	16 (4.06%)	>0.05	15 (10.00%)	<0.05
Moderate level of inadequate intake	202 (18.25%)	18 (13.43%)	>0.05	69 (17.51%)	>0.05	27 (18.00%)	>0.05
Low level of inadequate intake	482 (43.54%)	64 (47.76%)	>0.05	184 (46.70%)	>0.05	69 (46.00%)	>0.05
Almost no inadequate intake	371 (33.51%)	47 (35.07%)	>0.05	124 (31.47%)	>0.05	39 (26.00%)	>0.05
No inadequate intake	5 (0.45%)	1 (0.75%)	>0.05	1 (0.26%)	>0.05	0 (0.00%)	>0.05
total	1107 (100%)	134 (100%)	>0.05	394 (100%)	>0.05	150 (100%)	>0.05

Data were presented as counts with proportion (%). Abbreviations: DAQS, dietary antioxidant quality score; DBI-P, Chinese diet balance index for pregnancy; DQD, diet quality distance; HBS, high bound score; LBS, low bound score.

Improving dietary energy structure and poor dietary antioxidative property benefited the management of early maternal obesity, overweight and underweight

Next, we assessed the risk of abnormal maternal BMI in early pregnancy induced by inappropriate dietary energy. Firstly, a daily diet with excessive energy intake increased the risk of early maternal obesity (AOR, 1.49; 95%CI, 1.02-2.17) and overweight (AOR, 1.26; 95%CI, 0.99-1.60) (Table 5). Then, according to the Dietary Reference Intakes for China[19], the excessive energy intake among pregnant women could be induced by dietary energy from carbohydrates < 50% (AOR, 2.29; 95%CI, 1.86-2.83), protein > 20% (AOR, 1.91; 95%CI, 1.52-2.40), and fat > 30% (AOR, 2.20; 95%CI, 1.77-2.74) (Table 6). Inversely, energy from fat < 20% and unsaturated fatty acids < 3% was beneficial to restrict excessive energy intake (AOR, 0.42-0.74; 95%CI, 0.20-0.98) (Table 6).

On the other hand, the "high level of imbalanced dietary structure" increased the risk of early maternal underweight (AOR, 3.95; 95%CI, 1.42-10.95), and energy intake was important to maternal underweight, too. The daily diet with inadequate energy intake could be induced by energy from fat < 20% (AOR, 1.35; 95%CI, 1.02-1.78) and unsaturated fatty acids < 3% (AOR, 2.36; 95%CI, 1.09-5.13) (Table 6). Inversely, the inadequate energy intake could be controlled by dietary energy from carbohydrate < 50% (AOR, 0.44; 95%CI, 0.35-0.54), protein > 20% (AOR, 0.52; 95%CI, 95%CI, 0.42-0.66), and fat > 30% (AOR, 0.45; 95%CI, 0.37-0.57) (Table 6). More interestingly, we found out that the "very poor dietary antioxidative quality" was a significant risk factor for maternal underweight in early pregnancy (AOR, 2.80; 95%CI, 1.02-7.66) (Table 5), which implied that not only inadequate energy intake but also dietary antioxidative property should be concerned for managing underweight among pregnant women in China.

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Table 4 The intake of macronutrients, energy, and isoflavones among BMI groups

Dietary intake	Normal [as control]	Obesity	*P* value	Overweight	*P* value	Underweight	*P* value
Macronutrients							
Carbohydrate (g/day)	225.07 (163.97-319.08)	244.24 (176.80-376.91)	0.053	236.06 (156.96-352.97)	0.167	221.74 (145.72-324.81)	0.395
Protein (g/day)	103.41 (65.78-151.85)	115.88 (75.23-181.04)	0.011	107.13 (72.51-173.58)	0.051	89.71 (57.11-148.26)	0.065
Fat (g/day)	61.12 (36.91-98.59)	70.22 (44.19-114.01)	0.035	65.29 (39.67-102.28)	0.177	52.51 (31.47-89.95)	0.081
Cholesterol (mg/day)	508.75 (331.51-771.28)	525.41 (394.74-834.64)	0.062	542.24 (348.43-775.69)	0.288	413.50 (223.97-727.56)	0.001
SFA (g/day)	12.57 (8.34-18.48)	12.68 (8.55-20.65)	0.343	13.14 (8.80-19.41)	0.165	10.82 (6.11-18.17)	0.018
MUFA (g/day)	10.74 (6.78-17.41)	11.48 (7.30-20.85)	0.089	11.49 (7.55-19.48)	0.129	9.37 (5.27-16.31)	0.058
PUFA (g/day)	6.59 (3.71-10.59)	6.38 (4.21-11.77)	0.363	6.80 (3.95-11.07)	0.262	5.73 (2.82-9.76)	0.048
Energy (kcal/day)							
Total energy intake	1837.59 (1255.99-2629.99)	2026.32 (1383.32-2836.39)	0.014	1926.97 (1306.66-2794.13)	0.095	1627.14 (1037.45-2686.05)	0.139
Carbohydrate for energy	847.70 (612.79-1205.77)	910.71 (631.65-1426.97)	0.077	892.68 (589.24-1333.13)	0.193	838.15 (557.27-1224.19)	0.378
Protein for energy	414.63 (263.32-609.96)	463.51 (300.94-724.14)	0.011	428.37 (289.88-689.27)	0.051	360.95 (230.24-593.31)	0.065
Fat for energy	494.28 (281.72-813.62)	571.99 (338.32-909.96)	0.080	512.96 (306.58-855.17)	0.254	423.89 (253.52-769.95)	0.083
Isoflavones (mg/day)	1.43 (0.60-3.14)	1.25 (0.51-2.93)	0.462	1.31 (0.57-3.06)	0.487	1.14 (0.42-2.36)	0.012
Daidzein (mg/day)	2.05 (0.91-4.14)	1.81 (0.79-3.85)	0.375	1.93 (0.92-3.94)	0.627	1.50 (0.66-3.25)	0.006
Glycitein (mg/day)	0.42 (0.18-0.91)	0.40 (0.16-0.91)	0.805	0.38 (0.18-1.01)	0.770	0.34 (0.13-0.73)	0.016
Genistein (mg/day)	1.95 (0.72-4.54)	1.59 (0.58-3.87)	0.404	1.78 (0.63-4.38)	0.429	1.51 (0.43-3.32)	0.016

Data were presented as median (IQR). Daidzein, glycitein, and genistein are 3 major subtypes of isoflavones. Abbreviations: MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acid.

Table 5 The risk of abnormal maternal BMI in early pregnancy induced by abnormal energy intake and poor antioxidative diet

The risk factors for early abnormal BMI	UOR	P value	AOR	P value
The risk from energy intake				
Excessive energy to obesity	1.47 (1.03-2.11)	0.035	1.49 (1.02-2.17)	0.038
Excessive energy to overweight	1.28 (1.02-1.61)	0.037	1.26 (0.99-1.60)	0.056
Excessive energy to underweight	0.87 (0.62-1.24)	0.442	0.87 (0.61-1.25)	0.463
Inadequate energy to obesity	0.68 (0.47-0.97)	0.035	0.67 (0.46-0.98)	0.038
Inadequate energy to overweight	0.78 (0.62-0.99)	0.037	0.79 (0.63-1.01)	0.056
Inadequate energy to underweight	1.15 (0.81-1.63)	0.442	1.14 (0.80-1.64)	0.463
The risk from dietary antioxidative status				
Very poor quality to obesity	2.80 (0.72-10.86)	0.137	2.28 (0.55-9.46)	0.256
Very poor quality to overweight	1.26 (0.52-3.07)	0.611	1.19 (0.48-2.97)	0.704
Very poor quality to underweight	3.15 (1.17-8.50)	0.023	2.80 (1.02-7.66)	0.046
Low quality to obesity	0.48 (0.09-2.48)	0.383	0.51 (0.10-2.67)	0.426
Low quality to overweight	0.68 (0.33-1.39)	0.284	0.69 (0.33-1.43)	0.312
Low quality to underweight	0.85 (0.31-2.28)	0.739	0.74 (0.27-2.01)	0.552
High quality to obesity	1.81 (0.77-4.23)	0.172	1.71 (0.72-4.07)	0.222
High quality to overweight	1.01 (0.65-1.56)	0.963	1.00 (0.64-1.56)	0.988
High quality to underweight	0.90 (0.48-1.70)	0.754	0.93 (0.49-1.77)	0.823

The assessment of energy intake was referred to the Dietary Reference Intakes for China, which specified the daily energy requirement of Chinese pregnant women at different ages, gestational stages, and physical activity levels. The assessment of dietary antioxidative status based on the DAQS score in this study, and the degree of average quality was set as control. Abbreviations: AOR, adjusted odds ratio; DAQS, dietary antioxidant quality score; UOR, unadjusted odds ratio.

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Table 6 The risk of abnormal energy intake induced by different macronutrient-provided energy structure

Macronutrients-provided energy	Risk of excessive energy intake				Risk of inadequate energy intake			
	UOR	*P* value	AOR	*P* value	UOR	*P* value	AOR	*P* value
Carbohydrate for energy								
>65%	0.74 (0.52-1.06)	0.098	0.76 (0.53-1.10)	0.145	1.35 (0.95-1.93)	0.098	1.31 (0.91-1.88)	0.145
<50%	2.26 (1.84-2.78)	<0.001	2.29 (1.86-2.83)	<0.001	0.44 (0.36-0.54)	<0.001	0.44 (0.35-0.54)	<0.001
Protein for energy								
>20%	1.87 (1.50-2.34)	<0.001	1.91 (1.52-2.40)	<0.001	0.53 (0.43-0.67)	<0.001	0.52 (0.42-0.66)	<0.001
<10%	1.33 (0.22-8.06)	0.754	1.56 (0.26-9.49)	0.632	0.75 (0.12-4.54)	0.754	0.64 (0.11-3.92)	0.632
Fat for energy								
>30%	2.15 (1.74-2.67)	<0.001	2.20 (1.77-2.74)	<0.001	0.47 (0.38-0.58)	<0.001	0.45 (0.37-0.57)	<0.001
<20%	0.73 (0.55-0.95)	0.021	0.74 (0.56-0.98)	0.035	1.38 (1.05-1.81)	0.021	1.35 (1.02-1.78)	0.035
UFAs for energy								
>11%	0.98 (0.80-1.20)	0.805	0.97 (0.78-1.19)	0.740	1.03 (0.84-1.26)	0.805	1.04 (0.84-1.28)	0.740
<3%	0.42 (0.20-0.91)	0.028	0.42 (0.20-0.92)	0.030	2.36 (1.10-5.09)	0.028	2.36 (1.09-5.13)	0.030

Abbreviations: AOR, adjusted odds ratio; UFAs, unsaturated fatty acids; UOR, unadjusted odds ratio.

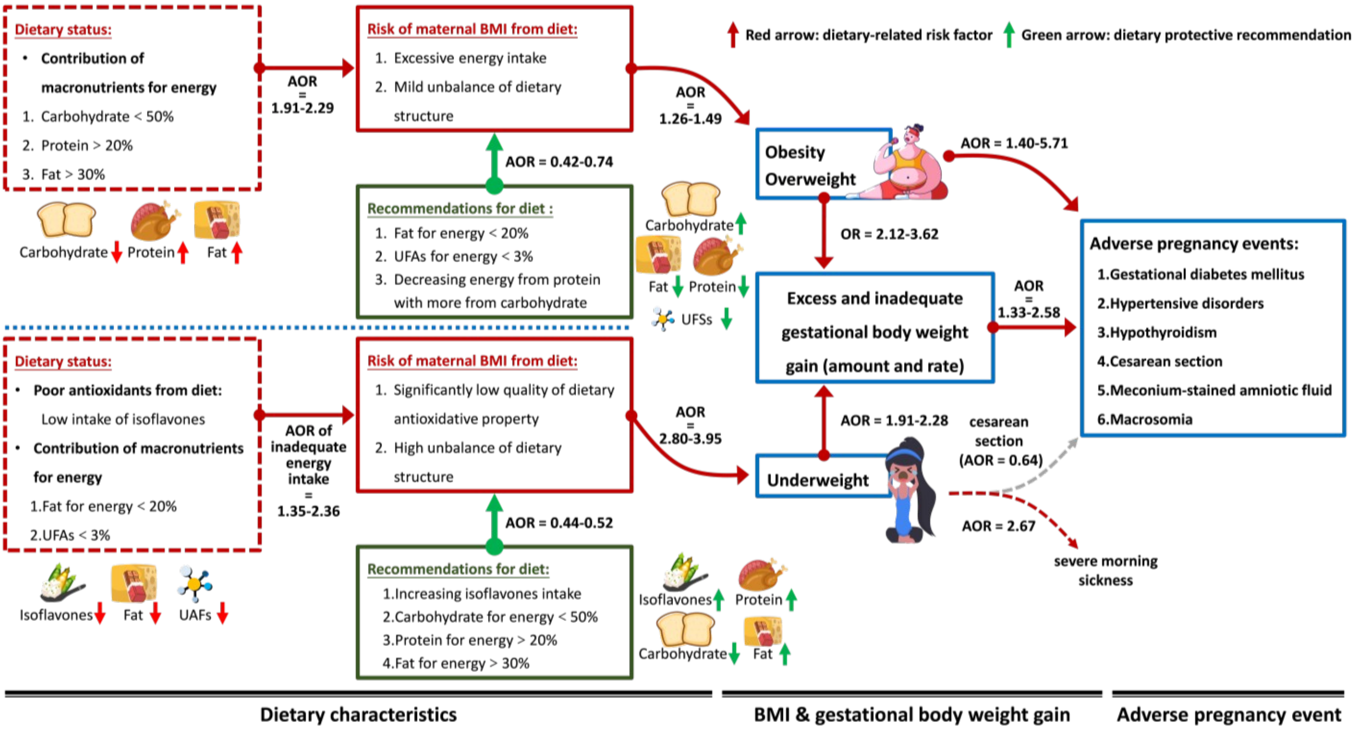

Fig. 2 The association among dietary status, maternal BMI, gestational body weight gain, and adverse pregnancy events. Covariates: age, gestational registration week, delivery week, parity, education level, physical activities, working status/income, smoking status, drinking status, and diabetes mellitus history. Abbreviations: AOR, adjusted odds ratio; UFAs, unsaturated fatty acids.

In short, improving dietary energy structure provided by macronutrients and antioxidative property contributed by dietary antioxidants (like isoflavones) were beneficial to the management of maternal BMI in early pregnancy (Fig. 2). To highlight the clinical significance of managing maternal BMI in early pregnancy by optimizing daily diet, next, we explored the connection between early maternal BMI and later pregnancy outcomes.

Abnormal maternal BMI without dietary management in early pregnancy was a risk factor for adverse pregnancy outcomes

In this study, pregnant women suffering from imbalanced diet-related obesity and overweight had a higher proportion of gestational diabetes mellitus than normal pregnant women (47.01% and 36.29% vs 22.40%, $P<0.05$), so did in hypertensive disorders of pregnancy (29.01% and 13.96% vs 5.69%, $P<0.05$), cesarean section (61.19% and 52.03% vs 40.83%, $P<0.05$), and

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preterm birth (9.70% and 8.88% vs 3.97%), as well as less neonate with normal birth weight (88.06% and 89.09% vs 93.32%, $P<0.05$) (Table S4†). Besides, obesity and overweight groups had fewer pregnant women with birth injury (29.10% and 32.74% vs 41.10%, $P<0.05$), which could be attributed to more women undergoing cesarean section and consequently controlling injury from natural vaginal delivery (Table S4†). Other pregnancy events showed no significant difference in proportion among BMI groups (Table S4†).

More importantly, maternal obesity increased the risk of gestational diabetes mellitus (AOR, 2.59; 95%CI, 1.76-3.80), hypertensive disorders of pregnancy (AOR, 5.71; 95%CI, 3.49-9.34), and cesarean section (AOR, 1.88; 95%CI, 1.28-2.75), respectively. Similarly, maternal overweight also increased the risk of gestational diabetes mellitus (AOR, 1.76; 95%CI, 1.36-2.28), hypertensive disorders of pregnancy (AOR, 2.35; 95%CI, 1.57-3.51), and cesarean section (AOR, 1.40; 95%CI, 1.10-1.78), respectively. Although the group of underweight pregnant women showed no significant results in the proportion of adverse pregnancy outcomes, however, maternal underweight might be disadvantageous to severe morning sickness (AOR, 2.67; 95%CI, 1.00-7.12) (Table 7).

To sum up, maternal overweight and obesity in early pregnancy showed a directly adverse association with gestational diabetes mellitus (AOR, 1.76-2.59; 95%CI,1.36-3.80), hypertensive disorders of pregnancy (AOR, 2.35-5.71; 95%CI, 1.57-9.34), and cesarean section (AOR, 1.40-1.88; 95%CI, 1.10-2.75), meanwhile, underweight could be related to severe morning sickness (AOR, 2.67; 95%CI, 1.00-7.12) (Fig. 2). Given the long period of pregnancy, directly associated early maternal BMI with adverse pregnancy events occurring a few months later was rough and incomplete. So, we further explore the role of gestational body weight gain as an intermediate bridge to explain these associations. The total amount of body weight gain before parturition and the average rate of body weight gain per week were both considered.

Total amount and weekly rate of gestational body weight gain among different maternal BMI groups

As for the total amount of body weight gain, obesity group had a higher proportion of excessive total gain amount than normal group (43.28% vs 32.52%), so did in overweight group (51.78% vs 32.52%). Whereas underweight group had a lower proportion of excessive total gain amount than normal group (23.32% vs 32.52%) (Table S5†). Moreover, obesity group had a higher proportion of inadequate total gain amount than normal group (24.63% vs 11.11%). Similar results were found in overweight (16.75% vs 11.11%) and underweight groups (20.00% vs 11.11%) (Table S5†).

As for the weekly rate of body weight gain, obesity group had a higher proportion of excessive weekly gain rate than normal group (44.77% vs 28.91%), so did in overweight group (51.01% vs 28.91%). Whereas underweight group had a lower proportion of excessive weekly gain rate than normal group (20.00% vs 28.91%) (Table S5†). Furthermore, obesity group had a higher proportion of inadequate weekly gain rate than normal group (24.63% vs 13.10%). Also, underweight group had more women with an inadequate weekly gain rate (20.00% vs 13.10%). However, overweight group showed on significant result in the proportion of inadequate weekly gain rate compared to normal group (Table S5†).

In general, obesity and overweight groups had more pregnant women with excessive and inadequate gestational body weight gain. Whereas inadequate weight gain was a notable problem in underweight group.

Gestational body weight gain could be the intermediate bridge to connect early maternal BMI and adverse pregnancy outcomes

Between early maternal BMI and further gestational body weight gain, obesity increased the risk of excessive total gain amount (AOR, 2.42; 95%CI, 1.58-3.72), inadequate total gain amount (AOR, 3.62; 95%CI, 2.14-6.12), excessive weekly gain rate (AOR, 2.82; 95%CI, 1.83-4.34), and inadequate weekly gain rate (AOR, 3.28; 95%CI, 1.95-5.51). Similarly, overweight increased the risk of excessive total gain amount (AOR, 3.00; 95%CI, 2.30-3.91), inadequate total gain amount (AOR, 2.45; 95%CI, 1.69-3.56), excessive weekly gain rate (AOR, 3.25; 95%CI, 2.49-4.24), and inadequate weekly gain rate (AOR, 2.12; 95%CI, 1.48-3.04). Whereas underweight only increased the risk of inadequate total gain amount (AOR, 1.91; 95%CI, 1.20-3.07) and inadequate weekly gain rate (AOR, 2.28; 95%CI, 1.48-3.51) (Table 8).

Between gestational body weight gain and later adverse pregnancy outcomes, the excessive total amount of weight gain increased the risk of hypertensive disorders (AOR, 2.08; 95%CI, 1.43-3.03), hypothyroidism (AOR, 1.44; 95%CI, 1.08-1.91), cesarean section (AOR, 1.33; 95%CI, 1.07-1.64), and macrosomia (AOR, 2.49; 95%CI, 1.48-4.17). Meanwhile, the inadequate total amount of weight gain increased the risk of gestational diabetes mellitus (AOR, 2.58; 95%CI, 1.91-3.49) (Table 9). Similarly, the excessive weekly rate of weight gain increased the risk of hypertensive disorders (AOR, 2.37; 95%CI, 1.62-3.47), hypothyroidism (AOR, 1.39; 95%CI, 1.04-1.85), cesarean section (AOR, 1.40; 95%CI, 1.13-1.74), and macrosomia (AOR, 2.16; 95%CI, 1.30-3.60). The inadequate weekly rate of weight gain increased the risk of gestational diabetes mellitus (AOR, 2.29; 95%CI, 1.72-3.06) (Table 9).

In short, following the timeline of gestation to delivery, abnormal maternal BMI in early pregnancy increased the risk of subsequently abnormal gestational body weight gain (AOR, 2.12-3.62; 95%CI, 1.20-6.12). Then, the abnormal weight gain further increased the risk of later adverse pregnancy outcomes, such as gestational diabetes mellitus, hypertensive disorders, hypothyroidism, cesarean section, and macrosomia (AOR, 1.33-2.58; 95%CI, 1.04-4.17). That is, gestational body weight gain could be the intermediate bridge for connecting early maternal BMI and adverse pregnancy outcomes, so it should be monitored based on Chinese localized standards of total gain amount and weekly gain rate. More importantly, management of maternal BMI in early pregnancy via the improvement of dietary structure (especially aimed at dietary energy and antioxidative property) could prevent these vicious causal associations among Chinese pregnant women from the very beginning (Fig. 2).

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Table 7 The risk of adverse pregnancy outcomes from abnormal maternal BMI in early pregnancy

Adverse pregnancy outcomes	Obesity				Overweight				Underweight			
	UOR	*P* value	AOR	*P* value	UOR	*P* value	AOR	*P* value	UOR	*P* value	AOR	*P* value
Morning sickness												
Severe	0.48 (0.17-1.34)	0.163	0.66 (0.23-1.90)	0.442	0.49 (0.22-1.09)	0.081	0.56 (0.25-1.26)	0.159	2.78 (1.06-7.30)	0.039	2.67 (1.00-7.12)	0.050
Moderate	0.58 (0.32-1.04)	0.069	0.74 (0.39-1.38)	0.338	1.23 (0.80-1.89)	0.344	1.36 (0.87-2.12)	0.173	2.14 (0.98-4.70)	0.057	1.93 (0.87-4.28)	0.104
Mild	0.60 (0.36-1.02)	0.057	0.80 (0.46-1.39)	0.421	1.03 (0.69-1.53)	0.905	1.16 (0.77-1.76)	0.471	1.79 (0.84-3.79)	0.131	1.61 (0.75-3.43)	0.222
Gestational diabetes mellitus	3.07 (2.13-4.44)	<0.001	2.59 (1.76-3.80)	<0.001	1.97 (1.54-2.53)	<0.001	1.76 (1.36-2.28)	<0.001	0.60 (0.37-0.96)	0.032	0.64 (0.40-1.03)	0.067
Hypertensive disorders of pregnancy	6.80 (4.33-10.68)	<0.001	5.71 (3.49-9.34)	<0.001	2.69 (1.84-3.94)	<0.001	2.35 (1.57-3.51)	<0.001	0.34 (0.11-1.09)	0.070	0.37 (0.11-1.19)	0.094
Thyroid disease												
Hypothyroidism	1.06 (0.65-1.72)	0.828	0.86 (0.51-1.44)	0.571	0.86 (0.62-1.19)	0.361	0.79 (0.56-1.10)	0.167	0.97 (0.60-1.56)	0.899	0.92 (0.57-1.49)	0.732
Hyperthyroidism	1.48 (0.43-5.14)	0.536	1.08 (0.29-4.07)	0.905	0.64 (0.22-1.92)	0.429	0.55 (0.18-1.70)	0.300	1.30 (0.38-4.51)	0.677	1.44 (0.41-5.08)	0.574
Cesarean section	2.29 (1.58-3.30)	<0.001	1.88 (1.28-2.75)	0.001	1.57 (1.25-1.98)	<0.001	1.40 (1.10-1.78)	0.006	0.62 (0.43-0.90)	0.011	0.64 (0.44-0.93)	0.019
Birth injury	0.59 (0.40-0.87)	0.008	0.96 (0.59-1.57)	0.883	0.70 (0.55-0.90)	0.004	0.85 (0.63-1.15)	0.299	1.07 (0.76-1.51)	0.715	0.76 (0.50-1.13)	0.176
Preterm birth	2.60 (1.36-4.96)	0.004	2.21 (0.11-45.18)	0.606	2.36 (1.49-3.73)	<0.001	3.40 (0.42-27.67)	0.252	0.49 (0.15-1.61)	0.241	0.59 (0.01-63.62)	0.824
Fetal distress	0.96 (0.54-1.72)	0.890	0.74 (0.39-1.41)	0.358	1.25 (0.88-1.77)	0.208	1.02 (0.69-1.50)	0.936	0.98 (0.57-1.71)	0.949	1.11 (0.59-2.06)	0.753
Premature rupture of fetal membranes	0.96 (0.62-1.48)	0.842	0.95 (0.60-1.52)	0.828	1.07 (0.82-1.41)	0.625	1.04 (0.78-1.39)	0.799	0.94 (0.62-1.42)	0.768	0.88 (0.58-1.36)	0.574
Postpartum hemorrhage	1.55 (0.59-4.10)	0.376	2.25 (0.81-6.24)	0.119	1.04 (0.50-2.17)	0.913	1.00 (0.46-2.17)	0.996	0.82 (0.25-2.72)	0.741	0.61 (0.17-2.13)	0.436
Meconium-stained amniotic fluid	0.78 (0.41-1.49)	0.449	0.80 (0.41-1.57)	0.515	0.98 (0.67-1.44)	0.935	1.00 (0.68-1.48)	0.998	1.26 (0.75-2.12)	0.377	1.23 (0.71-2.12)	0.457
Neonatal birth weight	1.89 (1.07-3.36)	0.029	1.37 (0.70-2.68)	0.352	1.71 (1.15-2.54)	0.008	1.37 (0.88-2.14)	0.160	0.79 (0.37-1.67)	0.530	0.86 (0.39-1.86)	0.695
Macrosomia	1.89 (0.86-4.16)	0.112	1.55 (0.66-3.63)	0.310	1.67 (0.97-2.89)	0.067	1.61 (0.91-2.84)	0.104	1.18 (0.49-2.85)	0.713	1.21 (0.49-2.99)	0.675
Low birth weight	1.89 (0.86-4.16)	0.112	0.97 (0.27-3.57)	0.967	1.75 (1.02-3.01)	0.043	0.90 (0.39-2.08)	0.812	0.39 (0.09-1.65)	0.202	0.44 (0.08-2.39)	0.342

Abbreviations: AOR, adjusted odds ratio; UOR, unadjusted odds ratio.

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Table 8 The risk of abnormal gestational body weight gain from maternal BMI in early pregnancy

Risk of abnormal weight gain from abnormal maternal BMI		Obesity	Overweight	Underweight
Excessive amount	UOR	2.34 (1.54-3.54)	2.85 (2.20-3.69)	0.71 (0.47-1.08)
	P value	<0.001	<0.001	0.111
	AOR	2.42 (1.58-3.72)	3.00 (2.30-3.91)	0.67 (0.44-1.02)
	P value	<0.001	<0.001	0.061
Inadequate amount	UOR	3.89 (2.38-6.38)	2.70 (1.89-3.85)	1.79 (1.13-2.83)
	P value	<0.001	<0.001	0.013
	AOR	3.62 (2.14-6.12)	2.45 (1.69-3.56)	1.91 (1.20-3.07)
	P value	<0.001	<0.001	0.007
Excessive rate	UOR	2.94 (1.93-4.47)	3.15 (2.43-4.08)	0.74 (0.48-1.15)
	P value	<0.001	<0.001	0.186
	AOR	2.82 (1.83-4.34)	3.25 (2.49-4.24)	0.70 (0.45-1.10)
	P value	<0.001	<0.001	0.124
Inadequate rate	UOR	3.56 (2.18-5.83)	2.25 (1.59-3.19)	2.13 (1.40-3.25)
	P value	<0.001	<0.001	<0.001
	AOR	3.28 (1.95-5.51)	2.12 (1.48-3.04)	2.28 (1.48-3.51)
	P value	<0.001	<0.001	<0.001

Abbreviations: AOR, adjusted odds ratio; UOR, unadjusted odds ratio.

Table 9 The risk of adverse pregnancy outcomes induced by abnormal gestational body weight gain

Risk of adverse pregnancy events		Excessive total gain amount	Inadequate total gain amount	Excessive weekly gain rate	Inadequate weekly gain rate
Gestational diabetes mellitus	UOR	0.73 (0.57-0.93)	2.75 (2.06-3.67)	0.76 (0.59-0.97)	2.43 (1.84-3.21)
	P value	0.011	<0.001	0.026	<0.001
	AOR	0.73 (0.57-0.94)	2.58 (1.91-3.49)	0.72 (0.56-0.93)	2.29 (1.72-3.06)
	P value	0.016	<0.001	0.011	<0.001
Hypertensive disorders in pregnancy	UOR	1.87 (1.31-2.68)	1.55 (0.95-2.54)	2.29 (1.60-3.29)	1.48 (0.90-2.42)
	P value	0.001	0.079	<0.001	0.119
	AOR	2.08 (1.43-3.03)	1.00 (0.58-1.74)	2.37 (1.62-3.47)	1.23 (0.72-2.09)
	P value	<0.001	0.988	<0.001	0.449
Hypothyroidism	UOR	1.47 (1.11-1.94)	1.25 (0.84-1.84)	1.42 (1.07-1.89)	1.30 (0.90-1.88)
	P value	0.007	0.271	0.015	0.166
	AOR	1.44 (1.08-1.91)	1.17 (0.79-1.75)	1.39 (1.04-1.85)	1.26 (0.87-1.84)
	P value	0.012	0.437	0.027	0.222
Cesarean section	UOR	1.30 (1.06-1.60)	0.99 (0.74-1.31)	1.43 (1.17-1.76)	1.05 (0.80-1.38)
	P value	0.011	0.936	0.001	0.732
	AOR	1.33 (1.07-1.64)	0.87 (0.65-1.17)	1.40 (1.13-1.74)	0.96 (0.72-1.27)
	P value	0.009	0.362	0.002	0.769
Meconium-stained amniotic fluid	UOR	0.87 (0.62-1.21)	0.81 (0.50-1.30)	0.91 (0.64-1.28)	1.05 (0.68-1.61)
	P value	0.400	0.378	0.579	0.829
	AOR	0.83 (0.59-1.17)	0.93 (0.57-1.52)	0.91 (0.64-1.29)	1.12 (0.72-1.74)
	P value	0.293	0.768	0.594	0.620
Macrosomia	UOR	2.52 (1.53-4.14)	0.15 (0.02-1.09)	2.16 (1.33-3.50)	0.11 (0.02-0.80)
	P value	<0.001	0.060	0.002	0.029
	AOR	2.49 (1.48-4.17)	0.12 (0.02-0.89)	2.16 (1.30-3.60)	0.09 (0.01-0.68)
	P value	0.001	0.038	0.003	0.020

Abbreviations: AOR, adjusted odds ratio; UOR, unadjusted odds ratio.

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Discussion

Due to distinct ethnic and lifestyles, different institutes and countries published localization standards of BMI for scientific purposes, for example, the ranges of BMI < 18.5, 18.5-24.9, 25.0-29.9, and ≥ 30.0 were deemed as underweight, normal weight, overweight, and obesity by the World Health Organization and the United Kingdom National Institute for Health and Care Excellence.[39] However, the BMI standard for Chinese was the foundation of the present study, which suggests <18.5, 18.5-24, 24-28, and ≥28 were classifications of BMI.[24,25] Based on that, our cohort from 2021-2022 in Beijing showed that the prevalence of maternal obesity, overweight, and underweight in early pregnancy were 7.51%, 22.07%, and 8.40%, respectively. The prevalence of abnormal maternal BMI in China was distinct from that in either developing areas (like Southern Ethiopia had 41.20% for undernutrition[40]), or developed countries (like the United States had 39.7% for obesity[41], and Japan had 21.7% for underweight[42]). That is, Chinese pregnant women had a unique epidemiological distribution of abnormal BMI, so strategies for managing maternal BMI should fit their characteristics.

Ideally, the management of pregnant women should be provided by nutritionists and obstetricians in the early stage.[41] Previous evidence suggested that dietary intervention and physical activity before the second trimester, not oral hypoglycemic agents (like metformin), might be an optimal strategy.[11] Nowadays, inappropriate energy intake among pregnant women is a worldwide problem. The structure of calorigenic nutrients and their food sources might be more important than a simple low-calorie diet.[43] In this study, overall maternal dietary characteristics were evaluated by dietary indexes like DBI-P and DQAS (which were previously validated in pregnant women in the Guangzhou Yuexiu birth cohort[31] and the participants of the Shanghai Women's Health Study[32]), meanwhile, detail features (like macronutrients and micronutrients intake) were also assessed. Turn out that maternal dietary characteristics were different from Western lifestyles or situations in developing areas.[40,41] We found out that dietary energy from carbohydrates <50%, protein >20%, and fat >30% were risk factors of excessive energy intake, which further increased the risk of maternal obesity and overweight in early pregnancy. Meanwhile, energy from fat <20% and unsaturated fatty acids <3% increased the risk of inadequate energy intake, which was not good news for maternal underweight. So, the dietary recommendations for Chinese pregnant women should not only serve for general ladies, but also need to be more specified to help women with obesity, overweight, and underweight.

Unlike previous literature considered obese women had a hidden hunger to micronutrients[44], in this study, the overall micronutrient intake in obesity and overweight groups was adequate. Except that underweight group had a 20.28% lower intake of isoflavones with a poor dietary antioxidative property contrasting to normal group. What's worse, we found that the poor dietary antioxidative property was a significant risk factor for maternal underweight in early pregnancy. Isoflavones, as a group of vital phytochemicals in soybeans and their products, had been widely reported to possess antioxidative capacity.[45-47] Mechanism study reported that isoflavones could activate the nuclear factor erythroid 2-related factor 2 (Nrf2) signaling pathway to mediate antioxidant responses.[37] Besides, in this study, underweight pregnant women had less dietary energy from unsaturated fatty acids could be a disadvantage to dietary antioxidative capacity. Additionally, other phytochemicals, including dietary fiber, flavonoids (luteolin, apigenin, quercetin, myricetin, and kaempferol), and anthocyanidins (delphinidin, cyanidin, and peonidin) was adequate among BMI groups (Table S3†). Unsaturated fatty acids (as essential fatty acids) not only provide energy for maintaining life but also be involved in the antioxidative system.[48-50] For example, docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) showed antioxidative activity via mitochondrial modulation.[48-50] Therefore, to reduce the risk of maternal underweight induced by poor dietary antioxidative property, the lower intake of isoflavones and the less energy from unsaturated fatty acids among Chinese pregnant women need to be concerned.

To highlight the clinical significance of managing maternal BMI in early pregnancy by optimizing daily diet, the connection between early maternal BMI and later pregnancy outcomes was further explored. Previous studies reported that abnormal BMI was related to postpartum weight retention in the United Kingdom[51] and offspring fat accumulation in Finland.[52] We found out that abnormal maternal BMI increased the risk of adverse events in China, such as gestational diabetes mellitus, hypertensive disorders, and cesarean section. So, abnormal BMI in early pregnancy is a serious threat to Chinese pregnant women.

Due to the whole pregnancy process having a long period, finding an intermediate bridge (like gestational body weight gain) to explain the direct connection between maternal BMI in early pregnancy and adverse pregnancy outcomes months later seems to be more reasonable.[53] Since 2009, the recommendations of gestational body weight gain from the American National Academy of Medicine (formerly known as the Institute of Medicine) were world widely used to maintain healthy pregnancy.[54-56] In detail, the American standards recommended a total amount of 12.5-18 kg, 11.5-16 kg, 7-11.5 kg, and 5-9 kg body weight gain to underweight, normal, overweight, and obese pregnant women, respectively.[56] Corresponding, the optimal average rates of weight gain were 0.51 (0.44-0.58) kg/week, 0.42 (0.35-0.50) kg/week, 0.28 (0.23-0.33) kg/week, and 0.22 (0.17-0.27) kg/week.[56] According to the American standards, data from more than 1 million pregnant women from America, Asia, and Europe showed that 47% of them had excessive gestational body weight gain, while 23% were inadequate.[21] However, previous literature in China based on the American version of body weight gain recommendations showed that neither diet intervention nor physical activity

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benefited the prevention of gestational diabetes mellitus, but only restricted gestational body weight gain.[57]

In 2021, the localized guidelines for gestational body weight gain in China were released.[24,25] Based on that, for Chinese maternal underweight, normal, overweight, and obesity, the optimal total amount of weight gain was 11-16 kg, 8-14 kg, 7-11 kg, and 5-9 kg, respectively, meanwhile, the optimal weekly rate of weight gain were 0.46 (0.37-0.56) kg/week, 0.37 (0.26-0.48) kg/week, 0.30 (0.22-0.37) kg/week, and 0.22 (0.15-0.30) kg/week, respectively.[58] According to the localized guidelines in China, 32.53%-51.78% of women in this study had an excessive total amount of weight gain and 11.11%-24.63% of them were inadequate, and the weekly rate of weight gain showed similar results. More importantly, over the time from gestation to delivery, abnormal maternal BMI in early pregnancy increased the risk of abnormal body weight gain, and subsequently, the abnormal body weight gain further increased the risk of adverse pregnancy outcomes. That is, gestational body weight gain could be the intermediate bridge to connect early maternal BMI and adverse pregnancy outcomes. Several mechanism studies showed that the changes in macronutrient metabolism, oxidative status, immune system, and biome homeostasis might play a role in these serial connections.[59,60] Besides, we found an interesting phenomenon that inadequate weight gain, not excess of that, was the risk factor for gestational diabetes mellitus, which might suggest that the guidelines of gestational body weight gain for managing this disease need extra attention.

Finally, based on our findings and the above evidence, we suggested that Chinese pregnant women with obesity or overweight should have more energy from carbohydrates (>65%) while less from protein (<10%) and fat (<20%). On the other hand, underweight pregnant women were recommended to increase their intake of dietary antioxidants (especially isoflavones) with more energy from fat (>30%) and unsaturated fatty acids (>11%). In the United States, berries and soluble fiber might be beneficial to ameliorating oxidative stress and metabolic complications during pregnancy[61], while we believe isoflavones-rich foods (like soybeans) were more crucial and recommended to underweight pregnant women in China.

Due to the present research still in a primary stage and could only provide exploratory results, In the future, we still need a large population with rigorous statistical analysis (like rational application of Bonferroni correction) to further verify and confirm the links between protein and obesity, as well as low isoflavone intake and maternal underweight. Previous researchers[62] suggested that red meat (rich in saturated protein, heme iron, and advanced glycation end products)[63] as well as metabolites of animal protein (like branched-chain and aromatic amino acids)[64,65] could be related to obesity and serum insulin, and might lead to insulin resistance, β-cell failure, and development of diabetes mellitus via provoking oxidative stress by upregulating iron load.[66] However, more underlying mechanisms among dietary characteristics (like isoflavones insufficient), maternal BMI, gestational body weight gain, and adverse pregnancy outcomes still need to be revealed, for example, whether dietary protein intake could affect hormonal regulation and thus influence obesity is noteworthy. Moreover, although the correlation between poor antioxidative property with low isoflavone intake and maternal underweight was found, whether there is a unique metabolic need as well as the molecular mechanism of this correlation is still missing puzzles. Furthermore, trying to normalize dietary energy requirements by body weight in further studies on dietary guidelines among the Chinese population might have unexpected findings. Besides, more pivotal food components and phytochemicals should be identified and applied to improve maternal and neonatal health. For example, in our previous study, natural bioactive components (like theabrownin from dark tea) significantly reversed obesity and alleviated oxidative stress by gut microbial-mediated serotonin signaling pathways[67,68], whether adding it to the daily diet could benefit pregnant women is still known.

Conclusions

Prevalence of maternal obesity, overweight, and underweight in early pregnancy was 7.51%, 22.07%, and 8.40% in this study, which showed distinct differences from the situation in Western countries and other developing areas. Less energy from carbohydrates (<50%) but more from protein (>20%) and fat (>30%) were problems to maternal obesity and overweight. The poor antioxidative diet with a significant 20.28% lower intake of isoflavones as well as imbalanced dietary structure with less energy from fat (<20%) and unsaturated fatty acids (<3%) were problems to maternal underweight. According to the body weight gain guidelines for Chinese pregnant women, gestational body weight gain was the intermediate bridge to connect early maternal BMI and adverse pregnancy outcomes, so it should be monitored throughout pregnancy in terms of total gain amount and weekly gain rate. To reduce the health burden during pregnancy in China, maternal obesity and overweight should have more energy from carbohydrates (>65%) while less from protein (<10%) and fat (<20%). For maternal underweight, increasing intake of dietary antioxidants (especially isoflavones) with more energy from fat (>30%) and unsaturated fatty acids (>11%) were recommended.

Author contributions

Conceptualization, H.-Y. Li; Data curation, H.-Y. Li, B.-J. Ding, J. Wang, X.-L. Yang, Z.-W. Ge, N. Wang, Y.-R. Li, Y.-X. Bi, C.-C. Wang, Z.-L. Shi, Y.-X. Wang, Y.-S. Wang, C. Li, and Z.-B. Peng; Formal analysis, H.-Y. Li; Funding acquisition, H.-Y. Li, B.-J. Ding, and Z.-X. Hong; Investigation, H.-Y. Li, B.-J. Ding, and X.-L. Yang; Methodology, H.-Y. Li; Project administration, B.-J. Ding and Z.-X. Hong; Resources, H.-Y. Li, B.-J. Ding, and Z.-X. Hong; Software, H.-Y. Li; Supervision, B.-J. Ding and Z.-X. Hong; Validation, H.-Y. Li; Visualization, H.-Y. Li; Writing-original draft, H.-Y. Li; Writing-review & editing, H.-Y. Li.

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Conflicts of interest

There are no conflicts to declare.

Data availability

The raw data files were uploaded to online Electronic supplementary information as an Excel file. However, we declare that the raw data of this research can only be browse and using as supplementary explanation of this paper. For any other purposes (like secondary analysis) on these raw data must contact the corresponding author on reasonable request first, and then achieving the authorization of both corresponding author and the Beijing Friendship Hospital, Capital Medical University.

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Data availability statements

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The raw data files were uploaded to online Electronic supplementary information as an Excel file. However, we declare that the raw data of this research can only be browse and using as supplementary explanation of this paper. For any other purposes (like secondary analysis) on these raw data must contact the corresponding author on reasonable request first, and then achieving the authorization of both corresponding author and the Beijing Friendship Hospital, Capital Medical University.

Zhong-Xin Hong (Chief Physician)

Department of Clinical Nutrition, Beijing Friendship Hospital, Capital Medical University

No.95, Yong'an Road, Xicheng District, Beijing 100050, China

Email: hongzhongxin@vip.sina.com. Tel. +86-18811695832

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