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Maternal dietary patterns during pregnancy derived by reduced-rank regression and birth weight in the Chinese population

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Abstract

Few studies have investigated the association between maternal dietary patterns (DP) during pregnancy, derived from reduced-rank regression (RRR), and fetal growth. This study aims to identify DP during pregnancy associated with macro- and micronutrient intakes, using the RRR method, and to examine their relationship with birth weight (BW). We used data of 7194 women from a large-scale cross-sectional survey in Northwest China. Dietary protein, carbohydrate, haem Fe density and the ratio of PUFA and MUFA:SFA were used as the intermediate variables in the RRR model to extract DP. Generalised estimating equation models were applied to evaluate the associations between DP and BW and related outcomes (including BW *z*-score, low birth weight (LBW) and small for gestational age (SGA)). Four DP during pregnancy were identified. Socio-demographically disadvantaged pregnant women were more likely to have lower BW and lower adherence to DP1 (high legumes, soyabean products, vegetables and animal-source foods, with relative low wheat and oils). Women with medium and high adherence to DP1 had significantly increased BW (medium 28·6 (95 % CI 7·1, 50·1); high 25·2 (95 % CI 2·7, 47·6)) and BW *z*-score and had significantly reduced risks of LBW and SGA. The associations were stronger among women with babies <3100 g. There is no association between other DP and outcomes. Higher adherence to the DP that was high in legumes, soyabean products, vegetables and animal-source foods was associated with improved BW in the Chinese pregnant women, particularly among those with disadvantageous socio-demographic conditions.

Key words: Pregnancy: Dietary patterns: Birth weight: Reduced-rank regression

Neonatal birth weight (BW) remains critical for the study of adverse pregnancy outcomes and the prediction of neonatal mortality and morbidity[1,2]. Low birth weight (LBW) and small for gestational age (SGA) are the two primary adverse birth outcomes determined by BW. LBW infant is the one born weighing <2500 g according to the WHO[3], and SGA is commonly defined as BW below the 10th percentile for gestational age and sex. Both LBW and SGA are the critical causes of perinatal and neonatal mortality and are related to many short-term morbidities (including respiratory diseases and necrotising enterocolitis) and long-term health issues (including cognitive deficiencies, mental retardation, cerebral palsy, diabetes and CVD)[3,4]. Therefore, poor fetal development in terms of BW could influence life-long health and take great economic costs and burdens for the society and the families involved in.

Maternal nutrition during pregnancy significantly contributes to fetal development. Dietary intakes of essential macro- and micronutrients are closely linked with pregnancy outcomes including BW, LBW and SGA, but the relationships are inconclusive[5]. For the macronutrients, Godfrey *et al.* observed a negative association between carbohydrate (CHO) intake in early pregnancy and BW[6], but a positive association between

Abbreviations: BW, birth weight; CHO, carbohydrate; DP, dietary pattern; LBW, low birth weight; PCA, principal component analysis; RRR, reduced-rank regression; SGA, small for gestational age.

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the percentage of total energy from CHO and BW was found in Cohen *et al.*'s study[7]. Discrepant findings in the relationship between maternal protein intake and BW were also presented in previous studies[6,8–11]. Watson *et al.* found a quadratic relationship between CHO, protein and fat intakes and BW[12]. In addition, recent evidence showed that the effect of protein on BW is non-linear and that a balanced diet fulfilling the minimum requirement for all macronutrients was ideal for avoiding fetal growth restriction[13]. These indicated the joint effect of macronutrients on fetal growth and could be an explanation for the inconsistent results in the previous studies. For the micronutrient, increased BW was associated with increasing pantothenic, biotin, Mg, vitamin D and vitamin B_{12} intakes[12]. Total Fe intake from food and supplements, prenatal Fe use and the dietary haem Fe intake were also in relation to improved BW and related outcomes such as LBW and SGA[14–16].

As stated above, evidence on the association between maternal nutrition and fetal growth usually focused on the effect of a single nutrient or a specific food component. Maternal dietary patterns (DP) could explicate the relationship more comprehensively due to the synergistic and antagonistic effects between the foods consumed are considered[17]. The principal component analyses (PCA) are a common method to obtain the DP. Evidence showed that DP derived from PCA are related to the susceptibility for developing LBW and SGA[18–20]. However, the PCA could not capture the patterns that were most strongly related to the outcome[21]. Instead, the reduced-rank regression (RRR)[17] is suitable for extracting the DP that were associated with the outcome. RRR is a statistical method used to derive disease-related DP, which determine a combination of foods (patterns) that better explain the variation of intermediate response variables (usually nutrients or biochemical markers) that are known to be predictive for disease[21]. It allows us to evaluate the combined effect of intermediate variables on the outcomes. To our knowledge, investigations on the association between maternal DP during pregnancy derived from the RRR and BW were rare. Accordingly, this study aims to identify maternal DP during pregnancy, derived by the RRR method, associated with dietary macronutrients and specific micronutrient intake and to examine their relationship with BW and related birth outcomes.

Method

Data source and participants

The study employed data from a large-scale cross-sectional survey conducted between August and November 2013 in Shaanxi Province of Northwest China. This population-based survey was aimed to investigate the risk factors of adverse pregnancy and birth outcomes. Detailed design and methods have been described elsewhere[22]. A brief sampling method was showed here. Women aged from 16 to 49 years, pregnant during 2010–2013 and had pregnant outcomes (including live birth, stillbirth and abortion) before the survey were enrolled using a stratified multistage random sampling method. According to the proportion of rural to urban residents, population size and fertility rate in Shaanxi, twenty counties and ten districts, were randomly sampled. In each sampled county, six villages each from six townships were randomly selected; in each sampled district, six communities each from three streets were randomly selected[22]. A total of 30 027 women were selected and interviewed by trained investigators to complete a structured questionnaire for collecting general information and characteristics during pregnancy. A sample of 7750 women who were pregnant during 2012–2013, had live births and delivered in less than 12 months were further interviewed to report their diets during pregnancy.

Ethics

This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by the Ethic Review Committee and Academic Committee of Xi'an Jiaotong University Health Science Center (approval no. 2012008). Written informed consent was obtained from all participants.

Dietary assessment

Maternal DP and the overall nutrient intakes from foods did not change appreciably from early to late pregnancy[23–25]. And for large-scale epidemiological surveys with multiple dietary exposures and outcomes, like our present study, diet assessment during the pregnancy at one time was reasonable, convenient and economical for both participants and investigators[23]. Evidence showed that the dietary information during pregnancy could be recalled with relatively good accuracy and reproducibility by mothers using FFQ even after years[26–29]. In this study, to ensure the accuracy of diet recall, the women who delivered in <12 months (median 3; 10th–90th percentiles 0–7) were asked to report their diet during pregnancy and the dietary information was collected by a 107-item semi-quantitative FFQ[22]. The FFQ was established according to the previously validated FFQ used for pregnant women in Shaanxi[30,31]. Pearson correlation coefficients between the validated FFQ and the average of 24-h recalls for all investigated nutrients, including the macronutrients and most of the micronutrients according to the Chinese Food Composition Tables, were ranged from 0·53 to 0·70. Pearson correlation coefficient was 0·61 for protein, 0·68 for CHO, 0·55 for fat and 0·65 for Fe. Among all the investigated food, five food items (animal oils, vegetable oils, salt, sugar and sauce) were recorded using open-ended frequency scales that marked as kg of use per month and the number of people regularly consuming them. The consumption frequencies of other 102 food items were reported by women through choosing one of the eight predefined categories which ranging from never to ≥2 times/d, along with identifying the portion sizes (large, medium or small) consumed per time based on food portion images[22]. Chinese Food Composition Tables[32] were referenced to transform daily food consumptions into total energy, macronutrient and micronutrient intakes, which were the sum of energy and nutrients in each food items. Total energy intake <2092 kJ or >20 920 kJ was regarded as implausible energy intake[31].

In this study, DP were obtained using RRR, which uses response variables as an intermediate between the dietary intake (predictor variables) and the outcome[17]. Compared with the PCA method used in many previous studies, the RRR reduces the dimension of predictor variables to the dimension of response variables and it could give better interpretations of the extracted DP by the explained variation in intermediate response variables that should be related to disease. With reference to the previous research, protein density (g/4184 kJ), CHO density (g/4184 kJ), the ratio of PUFA and MUFA density:SFA density ((PUFA+MUFA):SFA) and haem Fe density (mg/4184 kJ) were chosen as the response variables according to their associations with BW. Protein and CHO intake during pregnancy were linked with BW[12]. Intake of MUFA and PUFA may be related to the increased BW and reduced risk of LBW[5,12]. Increased maternal haem Fe intake may protect against LBW and SGA[14]. The 107 food items were consolidated into twenty-four food groups (wheat, rice, potatoes, legumes, soyabean products, green vegetables, other vegetables, fungi, fruits, nuts, red meat, poultry, processed meat, dairy products, eggs, fish, snacks, fast food, soft drinks, alcohol drinks, sweets, oils, solid fats and condiments) based on China Food Composition Tables and the logic of intake[32]. The twenty-four food groups (g/d) were considered as the predictor variables in the RRR model.

Outcome assessment

Neonatal information including birth date, sex, BW and gestational age was obtained by reviewing birth certificates. BW was measured with a baby scale with precision to the nearest 10 g. Gestational age at delivery was calculated according to the last menstrual period and was confirmed by ultrasound scans. The primary outcome of this study was BW, while the BW *z*-score, LBW and SGA were the secondary outcomes. The sex- and gestational age-adjusted BW *z*-score were calculated according to international standards developed by the International Fetal and Newborn Growth Consortium for the 21st Century[33]. LBW infant was defined as one born weighing <2500 g according to the WHO[3]. SGA was defined as BW below the 10th percentile for gestational age and sex according to the international standards[33].

Covariate assessment

We used face-to-face interviews to collect data on maternal characteristics using a structured questionnaire at the same time as diet information collection. We asked the participants to report maternal information during their pregnancy. Covariates mainly include two parts: (1) socio-demographic characteristics, including maternal age at delivery (<25, 25–34 and ≥35 years), education level (junior high school or below, senior high school and college or above), residence (urban and rural), occupation (farmers and others), per capita annual household income (low <8000, medium 8000–14 000 and high ≥14 000 Yuan, where 1 Yuan = 0·145 $US on 3 July 2019) and county (district) (twenty counties and ten districts); (2) health-related characteristics, including parity (primipara and multipara), smoking (yes and no), passive smoking (yes and no), alcohol consumption (yes and no), the times of antenatal visits (<5 and ≥5), pregnancy consultation (yes and no) and micronutrient supplementation (yes and no) including folic acid, Fe and multiple-micronutrient. Passive smoking was defined as being exposed to other people's cigarettes for more than 15 min/d. Pregnancy consultation was referred to the participation of health counselling that was related to maternal health care and fetal development before or during pregnancy. Women who consumed certain supplement more than 1 week during pregnancy were considered as users of such supplement, otherwise, were regarded as non-users.

Statistical analysis

Data set was established using Epidata 3.1 (The Epidata Association) with double entry. The RRR procedure was used to identify maternal DP during pregnancy, using the intake of twenty-four food groups (g/d) as predictor variables and protein density (g/4184 kJ), CHO density (g/4184 kJ), (PUFA+MUFA): SFA and haem Fe density (mg/4184 kJ) as response variables. Factor loadings derived from RRR were the measures of the association between food groups and the DP. Food groups with the absolute value of factor loading ≥0·15 were main contributors to the pattern. The association between each DP and the response variables was evaluated via Spearman's correlation coefficients. Factor scores were the evaluation of the adherence for each DP. Women were classified into three groups according to the tertiles of factor scores for each DP. T1, T2 and T3 were the low, medium and high adherence group, respectively. BW was divided into three groups by tertiles for comparing maternal characteristics. We used χ^2 tests for categorical variables and ANOVA tests for continuous variables to compare the maternal characteristics according to BW and the adherence to the DP.

Because of the hierarchical structure of the data derived from the stratified multistage random sampling design, generalised estimating equation models[34] with random effect at the county (district) level were applied to evaluate the associations between DP with the outcomes. Three models were established to estimate the change in BW and BW *z*-score (normal distribution and identity link function), OR for LBW and SGA (binomial distribution and logit link function), as well as their accompanying 95 % CI. Model 1 was the unadjusted model. Model 2 was adjusted for total energy intake and socio-demographic characteristics (including maternal age, education, residence and per capita annual household income). Model 3 was adjusted for all variables in model 2 and health-related factors in pregnancy (including parity, smoking, passive smoking, alcohol consumption, pregnancy consultation, number of antenatal visits, folic acid/Fe/multiple-micronutrient supplementation). Adjusted models for BW and LBW were additionally adjusted for sex and gestational age. To test for a linear trend, we used the tertiles of adherence to DP as a continuous variable. After examining the overall association between DP and BW, we further conducted the subgroup analysis to evaluate the relationship within different BW groups by tertiles.

All analyses were performed using SAS version 9.4 (SAS Institute). All statistical tests were two-tailed, and statistical significance was set as $P < 0·05$.

Results

Totally, 7194 eligible women were included in the final analysis, after excluding women who had multiple gestation (*n* 87), had

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no clear information on BW or gestational age (n 57), had gestational age of <33 or ≥43 weeks (n 64), had implausible BW (<1000 g or >5000 g) (n 8) and had an implausible total energy intake (>20 920 or <2092 kJ/d) (n 340) from women who completed the FFQ. Among the participants, 56·7 % of women were aged between 25 and 34 years and 63·2 % of women had junior high school or below educational level. Most of the participants were rural residents (76·6 %) and famers (73·5 %). 60·4 % of women were primiparous. The mean value of BW of the newborns was 3253·9 (SD 448·3) g, and the prevalence of LBW was 3·6 %. The gestational age ranged from 33^{+0} to 42^{+6} weeks, and 53·8 % newborn were boys. The mean value of BW z-score was –0·07 (SD 1·15), and the overall prevalence of SGA was 13·2 % (data were not shown in table).

Maternal characteristics of participants by birth weight

Maternal characteristics of participants by BW are displayed in Table 1. Women with lower BW were more likely to be aged below 25 or above 35 years, have junior high school or below educational level, be rural residents and farmers, have no pregnancy consultation and have less than five antenatal visits.

Dietary patterns

Table 2 shows the factor loadings of the food groups in the DP during the pregnancy derived by RRR, using protein density (g/4184 kJ), CHO density (g/4184 kJ), (PUFA+MUFA):SFA and haem Fe density (mg/4184 kJ) as response variables. Four DP were identified: DP1: high legumes, soyabean products, vegetables, meat, dairy products, eggs and fish, with relative low wheat and oils; DP2: high wheat, rice, potatoes, vegetables and fruits, with low nuts, red meat and oils; DP3: high wheat, potatoes, legumes, soyabean products, vegetables, nuts and fish, with low solid fat; DP4: high fruits, nuts, red meat, dairy products and soft drinks, with low legumes, eggs and solid fat. The four DP explained 25·5 % of the total variation in the food group intake and 72·4 % of the total variation in the response variables. DP1 and DP2 were the primary DP explaining 63·1 % (DP1 40·1 %; DP2 23·0 %) of variation of the response variables. DP1 score was correlated positively with protein and haem Fe density and negatively with CHO density and (PUFA+MUFA):SFA. The percentage of variation in the response variables explained by DP1 was 54·2 % for protein, 13·9 % for CHO, 48·1 % for (PUFA+MUFA):SFA and 45·2 % for haem Fe. DP2 score was correlated positively with protein and CHO and

Table 1. Maternal characteristics by birth weight (BW) tertiles among pregnant women in Shaanxi Province, Northwest China, 2010–2013
(Numbers and percentages; mean values and standard deviations)

	BW						
	T1 (<3100 g) (n 2385)		T2 (3100–3400 g) (n 2460)		T3 (≥3400 g) (n 2349)		
Characteristics	n	%	n	%	n	%	P*
Socio-demographic characteristics							
Age (years)							
<25	914	38·3	930	37·8	788	33·6	0·004
25–34	1039	54·9	1365	55·5	1407	59·9	
≥35	162	6·8	165	6·7	154	6·6	
Education							
Junior high school or below	1554	65·2	1574	64·0	1416	60·3	0·003
Senior high school	510	21·4	538	21·9	538	22·9	
College or above	321	13·5	348	14·2	395	16·8	
Rural residence	1906	79·9	1895	77·0	1708	72·7	<0·001
Farmers	1805	75·7	1789	72·7	1695	72·2	0·013
Per capita annual household income (RMB)							
Low	785	32·9	777	31·6	728	31·0	0·231
Medium	865	36·3	866	35·2	827	35·2	
High	735	30·8	817	33·2	794	33·8	
Health-related characteristics							
Primipara	1453	60·9	1508	61·3	1382	58·8	0·173
Pregnancy consultation†	602	25·2	737	29·9	705	30·0	<0·001
More than five antenatal visits	1703	71·4	1827	74·3	1765	75·1	0·009
Smoking	14	0·6	5	0·2	10	0·4	0·106
Passive smoking	562	23·6	563	22·9	494	21·0	0·097
Alcohol consumption	37	1·6	35	1·4	24	1·0	0·254
FA supplementation	1740	73·1	1842	74·9	1762	75·2	0·185
Fe supplementation	117	4·9	155	6·3	145	6·2	0·070
MMN supplementation	358	15·0	366	14·9	372	15·9	0·612
Pregnancy outcomes							
Male babies	1265	53·0	1309	53·2	1294	55·1	0·292
Gestational age (weeks)							
Mean	39·6		39·6		39·7		0·239
SD	1·3		1·2		1·1		

T1–T3, tertiles 1–3; RMB, Ren Min Bi; FA, folic acid; MMN, multiple-micronutrient.
* P values for the differences among groups were derived from χ^2 tests for categorical variables and ANOVA tests for continuous variables.
† Pregnancy consultation was referred to the participation of health counselling that related to maternal health care and fetal development before or during pregnancy.

Table 2. Factor loadings of food groups in the four dietary patterns (DP) derived by reduced-rank regression (RRR) among pregnant women in Shaanxi Province, Northwest China, 2010–2013†
(Factor loadings; Spearman's correlation coefficients; percentages of variation)

	DP1	DP2	DP3	DP4
Factor loadings of food groups				
Wheat	−0·11	0·56‡	0·19‡	0·14
Rice	0·06	0·30‡	−0·09	0·06
Potatoes	−0·01	0·20‡	0·18‡	−0·04
Legumes	0·16‡	0·13	0·32‡	−0·17‡
Soyabean products	0·25‡	0·03	0·33‡	−0·08
Green vegetables	0·18‡	0·11	0·31‡	−0·01
Other vegetables	0·15‡	0·31‡	0·41‡	−0·02
Fungi	0·23‡	0·02	0·26‡	0·11
Fruits	0·05	0·18‡	0·12	0·45‡
Nuts	0·06	−0·29‡	0·38‡	0·21‡
Red meats	0·48‡	−0·15‡	−0·04	0·39‡
Poultry	0·27‡	−0·10	0·11	0·05
Processed meats	0·20‡	−0·04	−0·03	−0·10
Dairy products	0·39‡	0·09	−0·11	0·22‡
Eggs	0·31‡	0·01	0·12	−0·31‡
Fish	0·33‡	−0·06	0·26‡	0·09
Snacks	0·10	0·04	0·02	0·05
Fast food	0·14	0·03	0·08	−0·07
Soft drinks	0·03	0·01	−0·02	0·17‡
Alcohol drinks	0·03	−0·03	−0·03	0·02
Sweets	0·05	−0·02	−0·09	−0·05
Oils	−0·14	−0·50‡	−0·08	0·09
Solid fats	0·11	−0·02	−0·30‡	−0·56‡
Condiments	0·01	−0·05	−0·06	−0·11
Spearman's correlation coefficient				
Protein density (g/4184 kJ)	0·74*	0·14*	0·43*	−0·08*
CHO density (g/4184 kJ)	−0·34*	0·82*	0·10*	0·09*
(PUFA+MUFA):SFA	−0·75*	−0·44*	0·30*	0·04*
Haem Fe density (mg/4184 kJ)	0·75*	−0·14*	−0·11*	0·15*
Percentage of variation of the food groups explained by the patterns	9·5	5·0	7·2	3·8
Percentage of variation of the response variables explained by the patterns				
Protein density (g/4184 kJ)	54·2	1·3	19·2	0·2
CHO density (g/4184 kJ)	13·1	65·6	1·0	1·0
(PUFA+MUFA):SFA	48·1	22·1	9·9	0·8
Haem Fe density (mg/4184 kJ)	45·2	3·0	1·0	3·8
Percentage of total variation of the response variables explained by the patterns	40·1	23·0	7·8	1·4

CHO, carbohydrate.
* $P < 0{\cdot}05$ for the correlations between factor score of DP and the response variables.
† Patterns were derived by RRR using dietary protein, CHO and haem Fe density, and PUFA and MUFA:SFA as the response variables and twenty-four food groups as the predictor variables. The DP obtained from RRR explained 25·5 % of the total variation in the food group intake and 72·4 % of the total variation in the response variables.
‡ Food groups with factor loadings' absolute value ≥0·15.

negatively with (PUFA+MUFA):SFA and haem Fe. It mainly explained the variation of CHO (65·6 %) and (PUFA+MUFA):SFA (22·1 %).

Maternal characteristics of participants according to adherence to the two main dietary patterns

Women with higher adherence to DP1 were more likely to be aged between 25 and 34 years, be better educated, be employed, live in the urban area, have high income level, be primiparous, have better antenatal care, have no passive smoking and have more micronutrient supplementation. Opposite characteristics were observed among women had higher adherence to DP2, including lived in rural areas, had lower income levels, were multiparous, had no pregnancy consultation and had less than five antenatal visits (Table 3).

Association between dietary patterns and birth weight and related outcomes

Compared with women with the low adherence to DP1, after adjusting for the covariates, those with the medium and high adherence had significant increases in BW (changes: medium 28·6 (95 % CI 7·1, 50·1); high 25·2 (95 % CI 2·7, 47·6); $P_{\text{trend}} = 0{\cdot}023$) and BW *z*-score (changes: medium 0·07 (95 % CI 0·02, 0·12); high 0·06 (95 % CI 0·01, 0·11); $P_{\text{trend}} = 0{\cdot}028$) and had significant reduction in risk of SGA (OR : medium 0·86 (95 % CI 0·77, 0·97); high 0·81 (95 % CI 0·70, 0·94); $P_{\text{trend}} = 0{\cdot}004$). In addition, the high adherence to DP1 had 35 % reduced risk of LBW (OR 0·65 (95 % CI 0·48, 0·87); $P_{\text{trend}} = 0{\cdot}005$). There is no association between DP2/DP3/DP4 and the outcomes (Table 4). Subgroup analysis showed that the association between adherence to DP1 and BW was observed in women with babies <3100 g and between 3100 and 3400 g, and as the rising of the adherence, the increases of BW were greater in women with babies <3100 g. There is no association between DP1 and BW among women with newborn ≥3400 g (online Supplementary Table S1).

Discussion

In the present population-based cross-sectional study conducted with 7194 pregnant women in Northwest China, four DP during pregnancy were identified using the RRR method. DP1 and DP2 were the two main DP that explained most of the variation in the response variables. Women with medium and/or high adherence to DP1 presented significantly higher BW and BW *z*-score and lower risk of LBW and SGA. The associations between DP1 and BW were observed in women with babies <3100 g and between 3100 and 3400 g, and it seemed to be stronger in the group of the newborn <3100 g. DP2, DP3 and DP4 were not associated with the outcomes.

DP in this study were derived from the RRR method with the response variables of dietary protein, CHO, haem Fe density and the ratio of (PUFA+MUFA):SFA based on their association with BW and related birth outcomes. The DP1 identified in this study presented a pattern high in dietary protein and haem Fe and low in CHO and the ratio of (PUFA+MUFA):SFA. This pattern comprehensively reflected the combined importance of dietary macronutrients and haem Fe intake on BW. Our finding of the positive association between the adherence to DP1 and BW was consistent with the relationship between dietary protein as well as haem Fe intake and BW shown in previous studies. Higher dietary protein intake or higher percentage of energy from protein during specific pregnancy phase was positively associated with BW[8,9,35]. Higher haem Fe significantly contributed to improved maternal Fe status[14], which was linked with reduced adverse birth outcomes such as LBW, preterm birth and SGA[36,37]. DP1 was negatively correlated with CHO density and

Table 3. Maternal characteristics of participants according to adherence to the two main dietary patterns (DP) among pregnant women in Shaanxi Province, Northwest China, 2010–2013 (Numbers and percentages; mean values and standard deviations)

	Adherence to DP1							Adherence to DP2						
	Low (*n* 2396)		Medium (*n* 2402)		High (*n* 2396)			Low (*n* 2395)		Medium (*n* 2404)		High (*n* 2395)		
Characteristics	*n*	%	*n*	%	*n*	%	*P**	*n*	%	*n*	%	*n*	%	*P**
Socio-demographic characteristics														
Age (years)														
<25	935	39·0	908	37·8	789	32·9	<0·001	920	38·4	865	36·0	847	35·4	0·074
25–34	1267	52·9	1345	56·0	1469	61·3		1313	54·8	1366	56·8	1402	58·5	
≥35	194	8·1	149	6·2	138	5·8		162	6·8	173	7·2	146	6·1	
Education														
Junior high school or below	1801	75·2	1559	64·9	1184	49·4	<0·001	1472	61·5	1553	64·6	1519	63·4	0·231
Senior high school	419	17·5	541	22·5	626	26·3		560	23·4	505	21·0	521	21·8	
College or above	176	7·4	302	12·6	586	24·5		363	15·2	346	14·4	355	14·8	
Rural residence	2138	89·2	1930	80·4	1441	60·1	<0·001	1730	72·2	1848	76·9	1931	80·6	<0·001
Farmers	1948	81·3	1785	74·3	1556	64·9	<0·001	1720	71·8	1775	73·8	1794	74·9	0·048
Per capita annual household income (RMB)														
Low	900	37·6	804	33·5	586	24·5	<0·001	710	29·7	772	32·1	808	33·7	0·002
Medium	911	38·0	855	35·6	792	33·1		840	35·1	848	35·3	870	36·3	
High	585	24·4	743	30·9	1018	42·5		845	35·3	784	32·6	717	29·9	
Health-related characteristics														
Primipara	1284	53·6	1427	59·4	1632	68·1	<0·001	1538	64·2	1433	59·6	1372	57·3	<0·001
Pregnancy consultation	499	20·8	647	26·9	898	37·5	<0·001	830	34·7	645	26·8	569	23·8	<0·001
More than five antenatal visits	1591	66·4	1775	73·9	1929	80·5	<0·001	1895	79·1	1730	72·0	1670	69·7	<0·001
Smoking	9	0·4	10	0·4	10	0·4	0·967	12	0·5	6	0·3	11	0·5	0·338
Passive smoking	626	26·1	557	23·2	436	18·2	<0·001	503	21·0	555	23·1	561	23·4	0·094
Alcohol consumption	22	0·9	32	1·3	42	1·8	0·042	39	1·6	32	1·3	25	1·0	0·211
FA supplementation	1666	69·6	1783	74·3	1895	79·3	<0·001	1854	77·6	1744	72·6	1746	72·9	<0·001
Fe supplementation	91	3·8	133	5·5	193	8·1	<0·001	131	5·5	140	5·8	146	6·1	0·649
MMN supplementation	303	12·7	356	14·9	437	18·3	<0·001	353	14·8	358	14·9	385	16·1	0·372
Pregnancy outcomes														
Birth weight (g)														
Mean	3225·1		3260·9		3275·7		<0·001	3254·3		3263·3		3244·0		0·432
SD	452·5		448·5		442·4			457·4		436·9		450·3		
Birth weight *z*-score														
Mean	−0·15		−0·05		−0·01		<0·001	−0·05		−0·06		−0·11		0·198
SD	1·15		1·16		1·13			1·16		1·13		1·16		
Low birth weight	103	4·3	86	3·6	68	2·8	0·025	98	4·1	73	3·0	86	3·6	0·144
Small for gestational age	361	15·1	312	13·0	280	11·7	0·002	336	14·0	300	12·5	317	13·2	0·285

RMB, Ren Min Bi; FA, folic acid; MMN, multiple-micronutrient.
* *P* values for the differences among groups were derived from χ^2 tests for categorical variables and ANOVA tests for continuous variables.

Table 4. Associations between dietary patterns (DP) and birth weight and related outcomes among pregnant women in Shaanxi Province, Northwest China, 2010–2013†
(Values are changes in grams, scores and odds ratios and 95 % confidence intervals)

	Adherence to DP					
Outcomes	Low	Medium		High		P_{trend}‡
Birth weight		Changes (g)	95 % CI	Changes (g)	95 % CI	
DP1						
Model 1§	Ref.	30·3*	8·8, 51·7	27·4*	2·4, 52·4	0·030
Model 2‖	Ref.	29·6*	8·0, 51·1	27·2*	3·7, 50·7	0·019
Model 3¶	Ref.	28·6*	7·1, 50·1	25·2*	2·7, 47·6	0·023
DP2						
Model 1	Ref.	14·4	−11·7, 40·5	−2·6	−31·6, 26·5	0·856
Model 2	Ref.	15·8	−10·5, 42·0	2·7	−25·5, 30·9	0·836
Model 3	Ref.	16·5	−10·0, 42·9	3·6	−25·2, 32·4	0·794
DP3						
Model 1	Ref.	−12·8	−39·1, 13·5	−8·9	−40·0, 22·3	0·580
Model 2	Ref.	−12·1	−38·0, 13·9	−6·3	−36·2, 23·5	0·665
Model 3	Ref.	−13·5	−40·0, 13·0	−7·5	−37·5, 22·6	0·614
DP4						
Model 1	Ref.	10·9	−15·6, 37·3	−15·3	−38·1, 7·6	0·199
Model 2	Ref.	11·3	−14·7, 37·3	−12·2	−37·0, 12·6	0·369
Model 3	Ref.	13·2	−12·7, 39·2	−11·3	−36·1, 13·5	0·411
Birth weight *z*-score		Changes in scores	95 % CI	Changes in scores	95 % CI	
DP1						
Model 1	Ref.	0·07*	0·01, 0·13	0·06*	0·01, 0·12	0·022
Model 2	Ref.	0·07*	0·01, 0·14	0·06*	0·01, 0·11	0·036
Model 3	Ref.	0·07*	0·02, 0·12	0·06*	0·01, 0·11	0·028
DP2						
Model 1	Ref.	0·02	−0·05, 0·09	−0·03	−0·10, 0·04	0·453
Model 2	Ref.	0·02	−0·05, 0·09	−0·02	−0·09, 0·05	0·549
Model 3	Ref.	0·02	−0·05, 0·09	−0·02	−0·09, 0·05	0·579
DP3						
Model 1	Ref.	−0·04	−0·12, 0·03	−0·03	−0·11, 0·05	0·480
Model 2	Ref.	−0·05	−0·12, 0·03	−0·03	−0·11, 0·05	0·470
Model 3	Ref.	−0·05	−0·12, 0·03	−0·03	−0·11, 0·05	0·437
DP4						
Model 1	Ref.	0·04	−0·02, 0·11	−0·02	−0·08, 0·04	0·582
Model 2	Ref.	0·05	−0·02, 0·12	−0·01	−0·07, 0·05	0·797
Model 3	Ref.	0·05	−0·02, 0·12	−0·01	−0·07, 0·06	0·833
LBW		OR	95 % CI	OR	95 % CI	
DP1						
Model 1§	Ref.	0·82	0·61, 1·08	0·64*	0·48, 0·86	0·003
Model 2‖	Ref.	0·81	0·61, 1·08	0·64*	0·47, 0·86	0·004
Model 3¶	Ref.	0·82	0·62, 1·09	0·65*	0·48, 0·87	0·005
DP2						
Model 1	Ref.	0·73	0·50, 1·08	0·87	0·64,1·20	0·409
Model 2	Ref.	0·73	0·49, 1·07	0·85	0·59, 1·21	0·358
Model 3	Ref.	0·73	0·50, 1·07	0·85	0·60,1·20	0·343
DP3						
Model 1	Ref.	1·16	0·87, 1·54	1·21	0·91, 1·61	0·176
Model 2	Ref.	1·15	0·87, 1·53	1·22	0·92, 1·63	0·167
Model 3	Ref.	1·15	0·86, 1·54	1·23	0·92, 1·64	0·155
DP4						
Model 1	Ref.	0·89	0·69, 1·16	0·89	0·70, 1·14	0·367
Model 2	Ref.	0·90	0·70, 1·17	0·91	0·72, 1·15	0·420
Model 3	Ref.	0·89	0·69, 1·14	0·90	0·72, 1·14	0·379
SGA						
DP1						
Model 1§	Ref.	0·86*	0·76, 0·97	0·80*	0·67, 0·94	0·007
Model 2‖	Ref.	0·86*	0·76, 0·97	0·80*	0·69, 0·93	0·003
Model 3¶	Ref.	0·86*	0·77, 0·97	0·81*	0·70, 0·94	0·004
DP2						
Model 1	Ref.	0·87	0·71, 1·05	0·93	0·78, 1·11	0·434
Model 2	Ref.	0·86	0·71, 1·05	0·91	0·75, 1·11	0·339
Model 3	Ref.	0·86	0·71, 1·05	0·91	0·74, 1·11	0·318
DP3						
Model 1	Ref.	1·08	0·92, 1·27	1·15	0·96, 1·36	0·118
Model 2	Ref.	1·09	0·92, 1·29	1·17	0·99, 1·36	0·058
Model 3	Ref.	1·09	0·91, 1·30	1·17	0·99, 1·37	0·060

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Table 4. (*Continued*)

Outcomes	Adherence to DP: Low	Medium		High		P_{trend}‡
DP4						
Model 1	Ref.	0·87	0·73, 1·04	0·91	0·78, 1·07	0·257
Model 2	Ref.	0·86	0·73, 1·02	0·90	0·77, 1·05	0·155
Model 3	Ref.	0·86	0·72, 1·02	0·90	0·76, 1·05	0·164

Ref., reference; LBW, low birth weight; SGA, small for gestational age.
* $P < 0.05$.
† Generalised estimating equation models with random effect at the county (district) level were used to estimate the change (95 % CI) for birth weight/birth weight *z*-score and OR and 95 % CI for LBW/SGA according to the adherence to the DP.
‡ Model 1 was an unadjusted model.
§ Model 2 was adjusted for total energy intake and socio-demographic characteristics (including maternal age, education, residence and per capita annual household income). Model 2 for birth weight and LBW was also adjusted for sex and gestational age.
∥ Model 3 was adjusted for all variables in model 2 and health-related factors in pregnancy (including parity, smoking, passive smoking, alcohol consumption, pregnancy consultation, number of antenatal visits, folic acid/Fe/multiple-micronutrient supplementation).
¶ P_{trend} was estimated using the tertiles of adherence to DP as a continuous independent variable in the models.

the ratio of (PUFA+MUFA):SFA, which indicate that lower dietary CHO and the ratio of (PUFA+MUFA):SFA were associated with increased BW. The relationship between CHO and BW was in accordance with the finding of Godfrey *et al.*'s study[6]. DP that was low in SFA and high in MUFA and *n*-3 PUFA was associated with decreased risk of delivering a fetal growth-restricted infant for weight[38].Our finding about the ratio of (PUFA+MUFA):SFA and BW was partially inconsistent with the previous study. This difference may be attributed to the joint effect of macro- and micronutrients on BW in the present study, rather than the impact from a single nutrient.

DP1 obtained in our study was characterised by high intakes of legumes, soyabean products, vegetables, meat, dairy products, eggs and fish, with relatively low intakes of wheat and oils. This was partially different from the recognised healthy pattern, for example, the pattern recommended by the USDA, with higher intakes of fruits, vegetables, grains (with at least half of the intake from whole grains), moderate intakes of protein (such as low-fat meat and poultry, beans and legumes, nuts and seeds, or fish) and low-fat dairy products, and a limited intake of oils (with a preference for MUFA and PUFA), refined grains, and added sugars[39]. However, the dominant food groups of DP1 have benefits on BW, as were previously reported. Higher meat and fish intakes were associated with increased BW[12]. Higher dairy intake during pregnancy was also related to the increased BW and reduced risk of LBW[35,40]. Legumes and vegetables are an important source of polyphenols, which acts as antioxidants to protect against oxidative stress and inflammation[41]. Elevated level of oxidative stress as well as inflammatory response could lead to pregnancy complications and result in adverse outcomes, including intra-uterine growth restriction, preterm birth and LBW[42]. Therefore, it is plausible that, for women with higher adherence to DP1, higher intake of plant foods rich in polyphenols may reduce the risk of adverse birth outcomes through its antioxidative and anti-inflammatory effect. We did not observe significant association between other DP and the outcomes. The factors (DP in this study) obtained by RRR usually are sorted by decreasing eigenvalues, and thus the first factor (DP1) of RRR explains more variation in response than any other linear function of predictors[17]. In this study, the DP1 explained the highest percentage (40·1 %) of the variation of response variables, which implied that the DP1 is more relevant to the intermediate variables that were related to the outcomes, and this may explain why the significant results were found restricted to DP1.

To the best of our knowledge, a few previous studies has investigated the association between DP during pregnancy derived by RRR and BW[39,43]. Because of the different intermediate variables, the DP extracted by RRR in existing studies were usually distinct from each other, so were the associations between DP and BW. Unlike our study, Starling *et al.* used the gestational weight gain and the fasting glucose as the response variables in the RRR method and reported that a pattern characterised by starchy vegetables, eggs, non-whole grains, and a low intake of dairy products, dark-green vegetables, whole grains and soya was associated with greater newborn BW and adiposity[39]. Our results were also different from the findings of several previous studies that used the PCA method to extract DP. Knudsen *et al.*'s research showed that a DP characterised by high intake of fruits, vegetables, fish and poultry was associated with decreased risk of SGA[44], while Thompson *et al.* exhibited that a DP composed of meat, potatoes, fruits (particularly citrus fruits), green vegetables, carrots, dairy products and water was protective for SGA[45]. Compared with studies that employed the PCA approach, the RRR method applied in our study, which used the macro- and micronutrients that are closely related to the outcomes as intermediate variables, could utilise and combine the finding of previous studies more efficiently and consider the relationship between diet and outcomes more comprehensively[17].

In our population, women with disadvantageous socio-demographic conditions and less antenatal care were more likely to have lower newborn BW. The associations between DP1 and BW were only observed in women with newborn <3100 g and between 3100 and 3400 g, and it seemed to be stronger in the group of the newborn <3100 g. This indicated that the DP1 mainly contributed to the betterment of BW among socio-demographically disadvantaged pregnant women. Women with disadvantageous socio-demographic conditions among our participants were more likely to have higher adherence to DP2, which was low in animal-source foods, rather than DP1. Considering the evidence that women with high adherence to a vegetarian DP had lower nutrient intakes compared with those who had high adherence to a balanced pattern[22], the inadequate nutrient intakes could be a major cause of the lower newborn BW among the socio-demographically disadvantaged group. DP1 in our study was high in both plant- and animal-source foods, and thus, an appropriate increase of the adherence to DP1 among Chinese pregnant women with disadvantageous socio-demographic conditions could efficiently improve the fetal development in terms of BW and reduce the risk of LBW and SGA through increasing their overall nutrient intakes.

The primary strength of the present study is that, for the first time, the associations between maternal DP during pregnancy derived by the RRR and BW in the Chinese population were examined, using dietary protein, CHO, haem Fe density and the ratio of (PUFA+MUFA):SFA as the response variables. The RRR method could extract the DP that were strongly related to the outcome by combining prior information and dietary information from the study. In addition, this is a representative and relatively large-scale study that investigated the effect of maternal DP during pregnancy on the adverse birth outcomes, from the background of the dietary culture in Northwest China. The cross-sectional study used a stratified multistage random sampling method to guarantee its representativeness in Shaanxi Province. The findings could be generalised to other regions in Northwest China according to the similarities in terms of economy, culture, lifestyle and diet habits in these regions and could partly reflect the dietary habits among pregnant women in China. Nonetheless, several limitations of the present study should be addressed. Firstly, the dietary and other maternal information during pregnancy was retrospectively self-reported by the mothers after delivery. Although the dietary information during pregnancy could be recalled rather well by mothers even after years[26–29], the possible influence of current diet on the accuracy of recall of past diet was inevitable, especially when the recall interval was long[46], and also we could not rule out the possible exposure misclassification due to recall bias. To minimise the recall bias, our study was limited to the women who were pregnant during 2012–2013 and delivered in <12 months to report their diet during pregnancy. Most of the mothers recalled their dietary intake during pregnancy at <7 months after delivery and half of them recalled at <3 months after delivery. In addition, we made efforts to help them recall accurately through face-to-face interviews by well-trained investigators and using detailed supporting materials such as food portion images and calendars to collect information. We also conducted a pilot study to test the survey materials and interviewers based on the detailed guides before the formal survey. All measures we adopted could ensure data quality to a certain extent. In addition, we believe that the possible exposure misclassification could be non-differential as the association between DP and BW was not known during the investigation, and it may cause the attenuation of the association. Secondly, we used FFQ to assess the dietary intakes, which may be not precise in estimating absolute intake of nutrients of individuals. However, at the population level, the FFQ method is good for measuring most of the common nutrients in pregnant women and can be used to rank dietary intakes[47,48]. The FFQ used in this study was established based on the previously validated FFQ used for pregnant women in the same region, which could guarantee its accuracy and reliability. Therefore, our FFQ could reflect the overall situation of dietary intakes and DP among our population. Moreover, compared with other dietary assessment methods such as food records and 24-h recalls, FFQ can reflect the dietary intakes rather well over a longer period and is more practical for the dietary assessment in large-scale population-based epidemiological investigations[30]. Thirdly, although we did the analysis by controlling for some potential confounders, there were still some unobserved or unknown confounders that may influence the association. For example, maternal pre-pregnancy BMI and gestational weight gain are associated with risks of adverse maternal and infant adverse outcomes[49]. Reduced risks of LBW and SGA were related to higher maternal pre-pregnancy BMI and excessive maternal gestational weight gain[50]. Also, the prenatal physical activity level of mothers was reported to be associated with reduced BW[51]. Unfortunately, the information about the factors mentioned above was not available in the present study, and thus we could not control for their impact on the relationship between maternal DP and birth outcomes. Therefore, our results were interpreted cautiously and require further assessment by prospective study. Finally, the cross-sectional design limited the interpretation on a real causal association. Further well-designed studies are suggested to explore the effect of DP during pregnancy on birth outcomes.

Conclusion

Findings in this study suggested the combined importance of macronutrients and haem Fe intake of DP on BW. During pregnancy, higher adherence to the DP that presented high intakes of legumes, soyabean products, vegetables and animal-source foods was associated with increased BW and BW z-score as well as reduced risk of LBW and SGA in the Chinese population, particularly among socio-demographically disadvantaged pregnant women. Targeted health education and intervention should be implemented to appropriately increase the adherence to this DP during pregnancy for the improvement of BW and its related birth outcomes.

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D. L., Y. C., S. D. and H. Y. conceived and designed the study; D. L., B. M., P. Q., S. L., R. Z., Q. Q., C. W., X. G. and Y. L. collected and cleared the data; D. L., S. D., B. M., L. Z. and P. Q. analysed and interpreted the data; D. L., Y. C., B. M., L. Z., S. L., R. Z., S. D. and H. Y. drafted and revised the manuscript. All authors reviewed and approved the final version of the manuscript.

The authors declare that there are no conflicts of interest.

Supplementary material

For supplementary material referred to in this article, please visit https://doi.org/10.1017/S0007114520000392

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