Journal of Pregnancy and Newborncare

ISSN: 2688-7487

Research Article

Association between Higher Intake of Fishes and Vegetables during Pregnancy and Full-Term Low Birth Weight Mediated By Placental Weight

This article was published in the following Scient Open Access Journal:
Journal of Pregnancy and Newborncare
Received December 12, 2019 ; **Accepted** December 24, 2019; **Published** December 31, 2019

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Abstract

Background: Previous studies have found that maternal dietary intake during pregnancy and placenta play important roles in low birth weight (LBW). However, whether the placenta may play an intermediary role in the association between maternal dietary intake during pregnancy and LBW is still unresolved. This study aimed to investigate this issue.

Methods: 345 pregnant women delivering full-term LBW infants (FT-LBW) and 1791 delivering full-term normal birth weight infants were investigated in this case-control study at Women and Childrens' Hospitals of Shenzhen and Foshan. We collected information about maternal dietary intake during pregnancy, socio-demographic characteristics, and pregnant outcomes. Binary logistic regression models were implemented to estimate the odds ratios (ORs) and 95% confidence intervals (CIs). The intermediary role of placental weight was examined by the bootstrapping procedure of PROCESS macro for SPSS.

Results: After controlling for the potential confounders, maternal higher daily intake of fishes (OR=0.43) and vegetables (OR=0.63) were significantly associated with a lower FT-LBW risk while more intake of milk (OR=1.60) was significantly associated with a higher FT-LBW risk during pregnancy. Furthermore, the mediation results showed that placental weight partially mediated the associations between maternal fishes and vegetables intake during pregnancy and FT-LBW, with the mediation proportion being 10.16% and 14.25% respectively.

Conclusions: Maternal higher intake of fishes and vegetables during pregnancy might reduce the risk of FT-LBW through placenta mediation partially.

Keywords: Dietary intake, Pregnancy, Low birth weight, Placental weight, Mediation

Background

Low birth weight (LBW), defined as a birth weight being less than 2500g regardless of gestational age [1], is considered to have a higher risk of neonatal, post-neonatal mortality and morbidity[2] as well as adult chronic diseases such as cardiovascular diseases, diabetes, obesity[3]. The underlying causes of LBW are multifactorial, including numerous maternal, fetal and placental factors [4]. There is ample evidence that maternal dietary intake during pregnancy influences foetal growth. For example, it was found that food and fortified food products could effectively increase birth weight and reduce the incidence of LBW[5] and higher maternal diet quality was related with longer body length at birth and a reduced risk of small for gestational age (SGA)[6, 7]. However, there are limited epidemiological studies suggesting the optimal maternal dietary intake for optimal infant birth weight, and the associations between them are insufficient and inconsistent.

The placenta plays an important role in birth outcomes [8]. Recent studies [9, 10] showed that placental development and function were influenced by maternal nutrition. It has been indicated that the placenta mediates the association of some antenatal factors with birth weight and foetal growth [11]. But it is not clear what role the placenta might play in the relationship between maternal dietary intake during pregnancy and FT-LBW.

Hence, this study aims to determine the relationship between maternal dietary intake during pregnancy and FT-LBW and further to explore the possible intermediary role of placenta in their associations.

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Methods

Study design and participants

A case-control study was conducted between September 2009 and March 2011 at the Foshan and Shenzhen Women and Children's Hospitals in Guangdong of China. We recruited a total of 3566 mother-infant pairs within 12–36 hours after delivery in the hospitals, the overall incidence of LBW was 9.67% in the study. However, mothers with characteristics as follows were excluded: (a) had multiple pregnancy; (b) delivered a new-born with malformation or stillbirth; (c) had obstetric complications, such as placental abruption, antepartum hemorrhage or pre-eclampsia; (d) had pre-existing chronic diseases, such as hypertension, diabetes, anaemia, renal disease, lung disease or hyperthyroidism; (e) lacked important information about exposure, outcomes or potential confounders; (f) had a preterm or post-term birth or delivered a baby with birth weight ≥ 4000g. The flowchart of participants is presented in (Figure 1). Finally, 2136 eligible mother-infant pairs participated in this study.

Data collection

All participants completed a structural questionnaire which includes socio-demographic characteristics, the history of health-related behaviours, reproductive history, medical history and maternal dietary intake during pregnancy. The information on newborns' birth weight and gender, maternal pregnancy complications (e.g. gestational diabetes and gestational hypertension which were diagnosed by doctors in the hospital information system), pre-pregnancy weight and height, gestational age, parity and placental weight was abstracted by reviewing medical records.

Measurement of birth weight and definition of FT-LBW

We derived birth weight and gestational age from medical records. Birth weight was measured immediately after delivery and routinely by midwifery nurses on an electronic scale in decagrams to the nearest 10g. LBW is defined as an infant birth weight of less than 2500 g [1], while normal birth weight infants (NBW) is no less than 2500g but less than 4000g, regardless of gestational age. The gestational age was estimated in combination with the last menstrual period (LMP) and the assessment of crown-rump length at the first-trimester ultrasound. Gestational age < 37w is defined as preterm, 37w ≤ gestational age < 42w is defined as full-term and gestational age ≥42w is defined as post-term. Finally, this study contained 2136 mother-infant pairs, including 1791 FT-NBW controls and 345 FT-LBW cases.

Measurement of the placental weight

Placental weight was abstracted from medical records. Midwifery nurses weighed the placenta, which was attached to the umbilical cord and membranes, on an electronic scale in decagrams immediately after delivery. In further analysis,

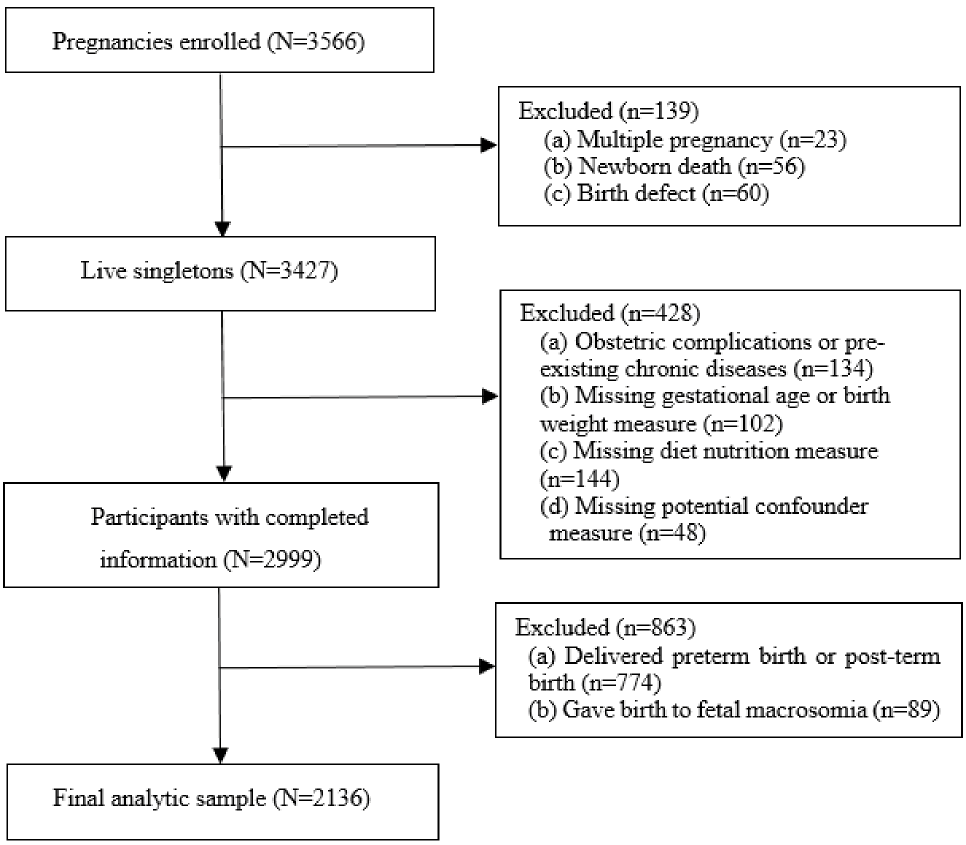


Figure 1: Flow chart of the analytic sample.

placental weight was standardized by its means and standard deviations to calculate the Z-score.

Measurement of maternal dietary intake during pregnancy

Trained medical students collected the information about maternal dietary intake during pregnancy at the interview. The participants were asked: "How much following diets did you take on average every day during pregnancy? 1) Rice/noodles (75g/bowl) and four response options were given for "1" = "no", "2" < "2 bowls/day", "3" = "2~4 bowls/day" and "4" > "4 bowls/day"; 2) Meat poultry(g) and four response options were given for "1" = "no", "2" < "100g/day", "3" = "100~200g/day" and "4" > "200g/day"; 3) Eggs and four response options were given for "1" = "no", "2" < "2 eggs/day", "3" = "2~4 eggs/day" and "4" > "4 eggs/day"; 4) Milk (240ml) and four response options were given for "1" = "no", "2" < "480ml/day", "3" = "480~960ml/day" and "4" > "960ml/day"; 5) Fishes(g) and four response options were given for "1" = "no", "2" < "100g/day", "3" = "100~200g/day" and "4" > "200g/day"; 6) Vegetables(g) and four response options were given for "1" = "no", "2" < "100g/day", "3" = "100~200g/day" and "4" > "200g/day"; 7) Fruits(g) and four response options were given for "1" = "no", "2" < "100g/day", "3" = "100~200g/day" and "4" > "200g/day"; and 8) Beans(g) and four response options were given for "1" = "no", "2" < "100g/day", "3" = "100~200g/day" and "4" > "200g/day".

Potential confounders

Referring to the literature [12, 13], second-hand smoke (SHS) exposure, pre-pregnancy body mass index (BMI), abortion history, gestational age and infant's gender were defined as the potential confounders in this study.

Statistical analysis

The continuous variables were described by means and standard deviations and the categorical variables were described by frequencies and percentages. We conducted chi-square/t-test to compare the overall characteristic balance between cases and controls. Daily dietary intake answers were divided into two categories since some options were too few to be analyzed, and combined with Zeyi Cao's [14] diet suggestions (Table 2). A series of binary logistic regression analysis were respectively conducted to explore the associations among placental weight, FT-LBW and maternal dietary intake during pregnancy.

Furthermore, a bootstrapping procedure of PROCESS macro for SPSS22.0 was performed using 5000 resample to investigate whether the placenta played an intermediary role in the relationship between maternal dietary intake during pregnancy and FT-LBW [11, 15]. In this method, if the upper and lower limits of the bias corrected 95% CI didn't contain zero, it was considered that the effect assessed by bias corrected bootstrap CI was significant. The potential confounders were controlled in all logistic regression models. Then the mediation proportion was calculated as follow [16]:

$$\frac{OR^{DE} \times (OR^{IE} - 1)}{OR^{DE} \times OR^{IE} - 1} \qquad (1)$$

OR^{DE} (direct effect) was the odd ratio of the main independent variable (maternal dietary intake during pregnancy in this study) to FT-LBW; OR^{IE} (indirect effect) was the exponent of the product by the partial coefficient of placental weight Z-score to FT-LBW and main independent variable to placental weight Z-score.

All of the P-values were two-sided, α (significance level) =0.05.

Results

Socio-demographic and obstetric characteristics of the participants

Table 1 depicts the overall balance of socio-demographic and obstetric characteristics between cases and controls. Apart from the significant lower birth weight, FT-LBW cases had a shorter gestational age and a lower placental weight than FT-NBW controls. Moreover, FT-LBW cases were more likely to have SHS exposure, be underweight before conception, and bear female infants, while less likely to have abortion history. There was no significant difference of other socio-demographic characteristics between cases and controls.

Association of maternal dietary intake during pregnancy with FT-LBW

The relationship between maternal dietary intake during pregnancy and FT-LBW is presented in (Table 2). After adjustment, maternal milk intake ≥ 480ml/day, fish intake ≥ 50g/day and

Table 1: Comparisons of socio-demographics and obstetric characteristics between FT-NBW and FT-LBW.

Characteristics	FT-NBW (n=1791)	FT-LBW (n=345)	t/χ^2	*P*-value
Maternal age, mean ± SD (years)	28.23 ± 4.40	27.99 ± 4.74	0.946	0.344
Ethnicity, n (%)				
Han	1744 (97.4)	333 (96.5)	0.777	0.378
Minority	47 (2.6)	12 (3.5)		
Education level, n (%)				
Junior high school or lower	541 (30.2)	120 (34.8)	3.094	0.213
High school	507 (28.3)	88 (25.5)		
College or higher	743 (41.5)	137 (39.7)		
Income (Chinese Yuan), n (%)				
≤3000	978 (54.6)	187 (54.2)	0.037	0.848
>3000	813 (45.4)	158 (45.8)		
SHS exposure, n (%)				
No	1159 (64.7)	175 (50.7)	24.062	< 0.001
Yes	632 (35.3)	170 (49.3)		
Abortion history, n (%)				
No	1056 (59.0)	226 (65.5)	5.165	0.023
Yes	735 (41.0)	119 (34.5)		
Parity, n (%)				
Primiparity	1338 (74.7)	268 (77.7)	1.505	0.220
Multiparity	453 (25.3)	77 (22.3)		
Pre-pregnancy BMI (kg/m2), n (%)				
Underweight (<18.5)	477 (26.6)	121 (35.1)	10.024	0.007
Normal(18.5≤BMI<24)	1146 (64.0)	197 (57.1)		
Overweight or obesity (≥24)	168 (9.4)	27 (7.8)		
Infant's gender, n (%)				
Male	924 (51.6)	140 (40.6)	14.108	< 0.001
Female	867 (48.4)	205 (59.4)		
Placental weight, mean ± SD (g)	526.33 ± 77.02	462.88 ± 59.15	11.10	< 0.001
Gestational age, mean ± SD (week)	38.95 ± 1.15	37.87 ± 1.01	17.69	< 0.001
Birth weight, mean ± SD (g)	3191.73 ± 375.25	2307.05 ± 202.62	62.87	< 0.001

vegetables intake >200g were still significantly associated with FT-LBW, but the associations of maternal daily intake of eggs ≥ 2 and fruits ≥ 200g were not significant.

Associations of placental weight with maternal dietary intake during pregnancy and FT-LBW

Table 3 shows the associations of placental weight with maternal dietary intake during pregnancy and FT-LBW. After adjustment, maternal rice or noodles intake > 300g/day was significantly associated with a lower placental weight, while maternal intake of fishes ≥ 50g/day, vegetables > 200g/day and beans ≥ 100g/day were significantly associated with a larger placental weight. Moreover, the negative association between placental weight and FT-LBW was significant whatever the potential confounders were controlled for or not.

Table 2: Logistic regression on associations between maternal dietary intake during pregnancy and FT-LBW.

Maternal dietary intake	FT-NBW (n=1791)	FT-LBW (n=345)	COR (95%CI)	AOR (95%CI)
	N. (%)	N. (%)		
Rice, noodles (g/d)				
≤300	1363(76.1)	275 (79.7)	1	1
>300	428 (23.9)	70 (20.3)	0.81 (0.61,1.08)	1.19 (0.86,1.63)
Meat poultry (g/d)				
<100	446 (24.9)	71 (20.6)	1	1
≥100	1345 (75.1)	274 (79.4)	1.28 (0.97,1.70)	1.28 (0.94,1.75)
Eggs (/d)				
<2	1461 (81.6)	258 (74.8)	1	1
≥2	330 (18.4)	87 (25.2)	1.49 (1.14,1.96)**	1.15 (0.84,1.56)
Milk (ml/d)				
<480	1442 (80.5)	239 (69.3)	1	1
≥480	349 (19.5)	106 (30.7)	1.83 (1.42,2.37)***	1.60 (1.19,2.13)**
Fishes (g/d)				
<50	116 (6.5)	37 (10.7)	1	1
≥50	1675 (93.6)	308 (89.3)	0.56 (0.38,0.82)**	0.43 (0.27,0.67)***
Vegetables (g/d)				
≤200	484 (27.0)	105 (30.4)	1	1
>200	1307 (73.0)	240 (69.6)	0.83 (0.62,0.94)*	0.63 (0.48,0.84)**
Fruits (g/d)				
≤200	959 (53.5)	163 (47.2)	1	1
>200	832 (46.5)	182 (52.8)	1.28 (1.02,1.62)*	1.25 (0.98,1.59)
Beans (g/d)				
<100	1353 (75.5)	243 (70.4)	1	1
≥100	438 (24.5)	102 (29.6)	1.29 (1.00,1.67)	1.16 (0.87,1.54)
Placental weight Z-score	0.11 ± 0.99	-0.71 ± 0.76	0.25 (0.19,0.33)***	0.30 (0.23,0.39)***

*: p<0.05; **: p<0.01; ***: p<0.001.
COR (crude odds ratio): without adjusting for SHS exposure, pre-pregnancy BMI, abortion history, infant's gender and gestational age.
AOR (adjusted odds ratio): with adjusting for SHS exposure, pre-pregnancy BMI, abortion history, infant's gender and gestational age.

Intermediary role of placental weight in the association between maternal dietary intake during pregnancy and FT-LBW

Daily fish intake ≥ 50g and vegetables > 200g during pregnancy were significantly associated with a lower FT-LBW risk after controlling for the potential confounders. When introducing the placental weight into the model, the strength of their associations decreased respectively. The bootstrap 95%CI results with bias-corrected suggested a significant mediation of placental weight in the association of daily fishes and vegetables intakes with FT-LBW, with the proportions of placental mediation being 10.16% and 14.25%, respectively. The mediation paths were shown in (Figure 2).

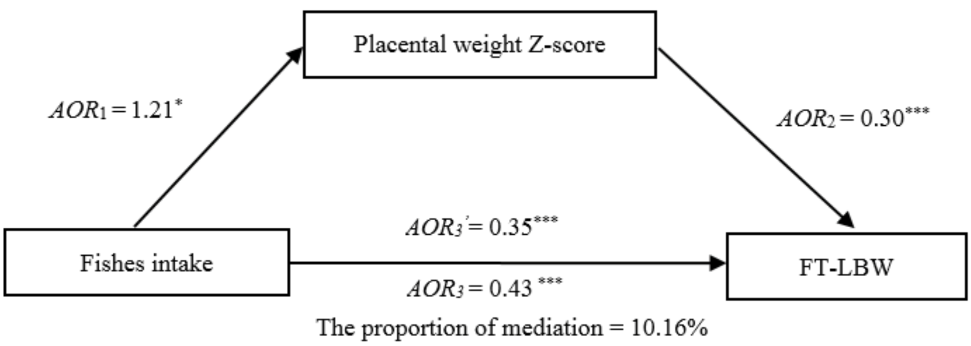
Discussions

In this case–control study, we found that maternal daily intake of more fishes and more vegetables during pregnancy decreased

Table 3: Associations of placental weight with maternal dietary intakes during pregnancy and FT-LBW.

Dependent variables	COR (95%CI)	AOR (95%CI)
FT-LBW (0=FT-NBW vs. 1=FT-LBW)	0.25 (0.19, 0.33)***	0.30 (0.23,0.39)***
Rice or noodles (0≤300 g/d vs. 1>300 g/d)	0.76 (0.67,0.86)***	0.73 (0.64,0.83)***
Meat poultry (0<100 g/d vs. 1≥100 g/d)	0.99 (0.87,1.12)	0.98 (0.86,1.11)
Eggs (0<2/d vs. 1≥2/d)	1.11 (0.97,1.28)	1.11 (0.97,1.28)
Milk (0<480 ml/d vs. 1≥480 ml/d)	0.88 (0.76,1.03)	0.88 (0.76,1.03)
Fishes (0<50 g/d vs. 1≥50 g/d)	1.22 (1.01,1.48)*	1.21 (1.01,1.47)*
Vegetables (0≤200g/d vs. 1> 200 g/d)	1.29 (1.14,1.46)***	1.31 (1.15,1.48)***
Fruits (0<200 g/d vs. 1≥200 g/d)	1.01 (0.92,1.12)	1.01 (0.91,1.12)
Beans (0<100g/d vs. 1≥100 g/d)	1.18 (1.04,1.33)**	1.17 (1.04,1.32)*

*: p<0.05; **: p<0.01; ***: p<0.001.
COR (crude odds ratio): without adjusting for SHS exposure, pre-pregnancy BMI, abortion history, infant's gender and gestational age.
AOR (adjusted odds ratio): with adjusting for SHS exposure, pre-pregnancy BMI, abortion history, infant's gender and gestational age.



*: p<0.05; **: p<0.01; ***: p<0.001.

Figure 2a: Simple mediation models for the relationships between maternal dietary intakes during pregnancy and FT-LBW, as mediating by placental weight.

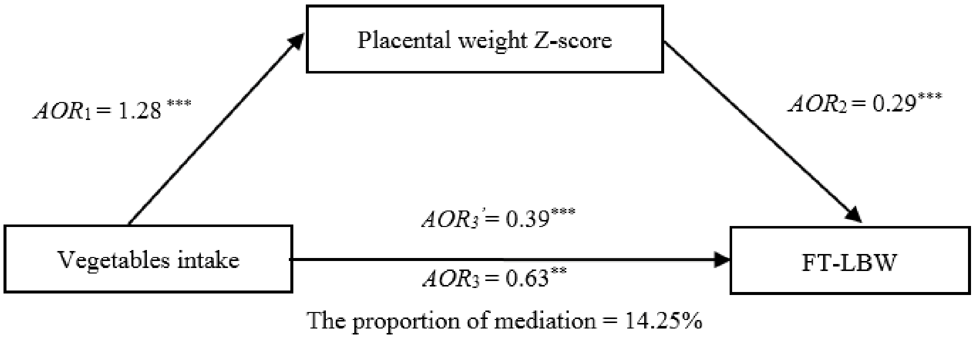


Figure 2b: AOR (adjusted odds ratio): with adjusting for SHS exposure, pre-pregnancy BMI, abortion history, infant's gender and gestational age.

the risk of FT-LBW, while their daily intake of more milk increased the risk of FT-LBW after controlling for the potential confounders. Further mediation analysis suggested that placental mediators were involved in the relationships between maternal intake of more fishes and more vegetables and FT-LBW with the intermediate effects being 10.16% and 14.25%, respectively.

A review summarized that the increased consumption of vegetables and fruits during pregnancy could increase birth weight and that only one prospective study from a highly developed area reported the increased risk of SGA birth by women with low vegetables intakes among four studies [17]. A recent study in Wuhan of China found that maternal fruit intake ≥300 g/day during the first trimester was associated with a higher LBW risk, but no significant association between vegetables intake during the first trimester and LBW [18]. Differently, our study showed that maternal intake of more vegetables significantly decreased the risk of FT-LBW whatever the potential confounders were controlled for or not, but more fruits significantly increased the risk of FT-LBW without adjusting for the potential confounders and this association became no significant (marginal significant with AOR=1.25, 95% CI =0.98~1.59) after adjusting for the potential confounders. However, it is inappropriate to compare the findings directly, because there is variability of dietary intake assessments in different pregnancy period, the categorization of fruits and vegetables intakes in different areas around the world, and the specific outcome examined (birth weight or LBW or SGA birth) across the studies [17]. Moreover, differences in study design and statistical analysis may also lead to different findings.

Up to now, results from prior studies on the relationships between maternal fish consumption and birth weight or LBW or SGA have not been consistent. For example, a case-control study [19] reported that fish intake was associated with a reduced SGA risk. Similarly, we found that maternal fish intake ≥50g/day significantly decreased the risk of FT-LBW. In contrast, Mendez MA et al [20] found that maternal consumption of canned tuna and crustaceans was associated with an increased SGA risk, while a study in Danish found an inverse association between birth weight and consumption of fatty fish and no association for lean fish [21]. Additionally, the Generation R study in Netherland found no consistent associations of fatty-fish, lean-fish or total-fish consumption with foetal growth characteristics during the second and third trimesters and at birth [22]. The differences in results across the aforementioned studies might due to the differences in quality and quantity of fish consumption and specific effects of different fish types, such as, fatty fish are high in beneficial n-3 fatty acid, protein, vitamin D, iodine and selenium, which are considered beneficial to the growth and development of the fetus [23]; but, shellfish may contain higher levels of environmental contaminants which may adversely affect foetal growth[24].

Several prior studies have consistently found a positive correlation between milk intake and birth weight gain. For example, two studies by Mannion CA et al [25] and Xue et al [26] respectively reported that for every extra cup of milk daily, there was an increase of 41 g and 6 g in birth weight. Similarly, the Generation R study [27] found that maternal milk intake of >3 glasses/day led to an 88 g higher birth weight than that with milk consumption of 0 to 1 glass/day. Additionally, a cohort study [28] suggested that moderate milk consumption relative to none or very low intake, was positively associated with foetal growth and infant birth weight. Another prospective study in South Asian Indian population indicated that milk products, and especially protein from milk product was positively associated with birth weight [29]. However, most studies treated birth weight as a continuous variable, and only few studies assessed the relationship between milk intake and SGA risk. For example, a case-control study [30] indicated that milk consumption was inversely associated with SGA risk. A prospective cohort study among 1175 Spain women [31] found that women who gave birth to SGA infants consumed 315.9 g/d of dairy products, while women with appropriate size for gestational age infants consumed 590.3 g/d and that an increased dairy products intake by 100 g/day during the first half of pregnancy decreased the risk of SGA by 11.0% [31]. Unfortunately, our study found an inverse association between more milk intake and the FT-LBW risk. One reason might be owed to that we just assessed the total milk consumption, and did not divide into milk and milk products that might contains some ingredients being optimal for different situations[32]. Another reason might be due to FT-LBW used in our study and SGA used by prior studies. Furthermore, we retrospectively recalled maternal milk intake, and pregnant women might intake more milk after their fetuses were diagnosed as intrauterine growth restriction (IUGR), which might lead to an inverse causal relationship between maternal milk intake and FT-LBW. Thus, it would be necessary to conduct higher validity studies to assess the relationship between maternal milk intake and FT-LBW.

There is abundant animal experimental evidence that placental weight is associated with dietary intake during pregnancy. A review [33] summarized that the reduction of caloric intake by 30–50% relative to controls throughout most of pregnancy resulted in an average feto-placental weight of 65–90% of controls near term. A series of experimental studies showed that isocaloric low protein diets intake throughout gestation had lower placental weight [34-36]. Consistent with previous researches, we also found that more fish and beans intake during pregnancy was correlated with higher placental weight. In addition, several studies demonstrated that feeding mice a diet rich in fat and sugar throughout pregnancy reduced the growth of placenta near term [33]. Similarly, our study found that maternal higher intake of rice or noodles had lower placental weight. More interestingly, maternal intake of more vegetables was positively associated with placental weight, which may be due to that vegetables are nutrient-dense foods containing a number of essential nutrients and bioactive substances, some of which might be important for placental development [37]. Taken together, the aforementioned findings demonstrated that maternal nutrition status during pregnancy may play an important role in determining placental growth.

It has been well documented that a positive association exists between foetal weight in late gestation and placental weight, as a proxy measure of the placental nutrient supply [33]. For example, some studies have showed coincident results that NBW controls had much larger placental weight than LBW cases [38, 39]. Besides, a previous study found gross placental measures including placental weight accounted for 39.1% of birth weight variation [40]. In agreement with these findings, our results showed that a lower placental weight was significantly correlated with a higher FT-LBW risk.

There is strong epidemiological evidence that the placenta plays an intermediary role in the influence of prenatal factors on foetal growth. Our previous studies suggested that placental weight mediated the relationship between maternal SHS exposure during pregnancy and SGA [11], and the relationship between prenatal exposure to cooking oil fumes and FT-LBW [15]. Additionally, it was found that the placenta mediated the association between prenatal air pollution exposure and birth weight [41]. Analogously, our mediation results showed that placental weight partially mediated the relationships between maternal fishes and vegetables intake and FT-LBW.

However, what's the mechanism the placenta mediates the effect of maternal intake on FT-LBW through? It's well known that foetal growth depends on the nutrient transport of placenta to a great extent and that the size, structure and function of placenta can all affect the nutrient transport ability [42]. Fishes and vegetables contain various nutrients considered to be beneficial for placental development, which include polyunsaturated n-3 fatty acids, protein, zinc and so on [37]. Once pregnant women don't take enough fishes or vegetables, it can cause a series of damages in placenta. Such as, micronutrient deficiencies is associated with oxidative stress of the placenta [43], zinc deficiency can reduce trophoblast differentiation, placental weight, and change protein expression in placenta [44]. Moreover, a recent review indicated that maternal deficiency of folate, vitamin A, vitamin D, iron and vitamin B12 had pro-inflammatory effects in the placenta [45]. Furthermore, anther review showed that maternal dietary n-3 polyunsaturated fatty acid supplementation during rat pregnancy could decrease placental oxidative damage and increase placental levels of pro-resolving mediators, effects associated with enhanced foetal and placental growth[46]. As a result, the damaged or underdeveloped placenta may not be able to deliver enough oxygen and nutrients from the mother to the fetus [47], leading to IUGR or LBW eventually [48].

Several limitations should be acknowledged in this study. First, the whole subjects coming from two women's and children's hospitals leads to selection bias, which may limit the universality of our results. Second, information bias might have been introduced by retrospectively collected information on maternal dietary intake. Third, maternal dietary intake was measured by asking pregnant women “How much following seven diets did you take every day during pregnancy?” not using food frequency questionnaire (FFQ) and we did not consider the influence of season on dietary, which might prevent us from assessing the effect of each specific nutrient. Fourth, although there is well-established evidence that placental weight is related to foetal growth, this study found that placental weight only mediated the relationship between maternal fishes and vegetables intake and LBW by 10.16% and 14.25% respectively. Placental pathologies may have led to a more substantial mediating effect, such as placental vascular pathology, placental oxidative damage, placental inflammation, and abnormal protein expression in placenta. Fifth, the nutrient transport ability of the placenta relies not only on its size but also on uteroplacental and umbilical blood flow as well as the morphology, the thickness, exchange area, and metabolism of the placenta [33], but our study just measured placental weight. Thus, further studies are needed to investigate more comprehensive placental parameters. Sixth, we have simplified the assumption of influence for a single direction in the maternal-placental-foetal unit. As foetal growth can affect placental growth in turn, this may also be the reason for the partial mediation found in our study. Seventh, as it was a case-control study, the causal relationship between maternal dietary intake and FT-LBW should be further exercised. Finally, although many potential confounders had been controlled, residual confounders caused by imprecisely measured or unmeasured confounders could not be excluded. Of course, these confounders should be taken into account in future studies.

Conclusions

In summary, our findings supported that placental weight played a partially intermediary role in the relationship between maternal dietary intake during pregnancy and FT-LBW and that different diets might have different effects on the FT-LBW risk.

List of abbreviations

LBW	Low birth weight
NBW	Normal birth weight
FT-LBW	Full-term low birth weight
FT-NBW	Full-term normal birth weight
LMP	Last menstrual period
SHS	Second-hand smoke
BMI	Body mass index
SGA	Small for gestational age

IUGR	Intrauterine growth restriction
FFQ	Food frequency questionnaire

Declarations

Ethics approval and consent to participate

All the participants had signed informed consent forms. And this study was approved by the Institutional Review Board of the School of Public Health, Sun Yat-sen University in Guangzhou, China and conducted in accordance with the Declaration of Helsinki.

Competing interests

The authors declare that they have no competing interests.

Funding

This work was funded by the National Natural Science Foundation of China (Grant Numbers 30872164 & 81172758).

Acknowledgements

The authors acknowledge the support of the Shenzhen Women and Children's Hospital and Foshan Women and Children's Hospital.

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