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Association of Pre-pregnancy BMI and Gestational Weight Gain with Neonatal Body Size: A Cross-Sectional Study

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Abstract

Background: Pre-pregnancy BMI and GWG partially reflect maternal nutrition. The study aimed to explore the effects of pre-pregnancy BMI and GWG on the body size of neonates at birth.

Methods: A total of 546 mothers and their babies were selected from August 2017 to April 2018 at Obstetrical Department of the 3rd Affiliated Hospital of Zhengzhou University. The levels of leptin and adiponectin in cord blood were measured. The mass of placenta was evaluated based on the size. The maternal subjects were defined as low (BMI<18.5), normal (18.5≤BMI<25.0) and overweight/ obese (BMI≥25.0) groups. Moreover, the maternal subjects were divided into low, normal and high GWG groups corresponding to the guidelines of GWG. The neonates were divided into small (SGA), large (LGA) and appropriate (AGA) for gestational age groups based on their birth weight and gestational weeks.

Results: The incidence of SGA was higher in low pre-pregnant weight group than that in normal and overweight/obese groups (both $P<0.05$). The incidence of LGA was higher in high GWG group than that in normal and low GWG groups (both $P<0.05$). The correlation analysis showed that the birth weight (BW), body length (BL), head circumference (HC), and Ponderal Index (PI) of neonates were positively correlated with pre-pregnancy BMI and GWG ($P<0.05$, $P<0.01$). Neonatal BW, BL, HC, PI, placental weight and placental volume were positively correlated with the levels of adiponectin and leptin in umbilical cord blood respectively ($P<0.05$).

Conclusions: Pre-pregnancy BMI and GWG are positively correlated with the full term neonatal size. It is crucial for neonatal physical development to maintain appropriate BW before and during pregnancy. The adiponectin and leptin in cord blood were positively correlated with neonatal physical development suggests that both them play an important role in regulating fetal growth and development.

Keywords: Gestational Weight Gain; LGA; BMI; SGA

Introduction

For the newborns, birth weight (BW), body length (BL), and head circumference (HC) are the most intuitive indicators of physical development. Abnormal physical development not only increases the risk of neonatal illness or death, but also significantly affects the occurrence of several chronic diseases in childhood/adulthood [1]. Adequate maternal nutrition plays a crucial role in providing nourished uterine environment for fetal development. Inadequacy or deficiency of maternal nutrition is associated with disruption of fetoplacental exchange. Maternal nutrition not only impacts neonatal development, but also has a long term influence on his/her health till adulthood [2]. Several epidemiological investigations and experimental studies confirmed that malnutrition during pregnancy will cause neonatal organ dysplasia, endocrine disorder, and even some chronic diseases during adulthood [3-6]. Optimized nutrition at early life, especially during fetal period is the most important factor for one's whole life. Some studies have indicated that nutrition at early stage of life has an impact on the development of some chronic non-communicated diseases at adulthood, such as obesity, diabetes, gout, hypertension, and coronary heart disease [7,8].

As the critical parameter of prenatal care, gestational weight gain (GWG) consisted of fetus, placenta, amniotic fluid, maternal adipose tissue and breast tissue growth, could reflect the health and nutrition condition of the pregnant women. Other researches showed that maternal malnutrition could influence neonatal development and even increase the incidence of low BW, while maternal over nutrition and excessive GWG also increases the risk of adverse birth outcomes [9-11].

Reasonable dietary intake during gestation is important for appropriate neonatal growth and also helpful to prevent the chronic diseases in the adulthood. Up to date, the data regarding the effect of pre-pregnant body mass index (BMI) and GWG on neonatal physical development were limited. Therefore, this study would explore the association of pre-pregnant BMI and GWG with neonatal development.

Methods

Subject inclusion and information collection

A cross-sectional study was conducted. The subjects were the pregnant women who planned to deliver their babies at Obstetrical Department of the 3rd Affiliated Hospital of Zhengzhou University, from August 2017 to April 2018. The inclusion criteria were monocyesis and full-term delivery without significant diseases both of the mother and baby. The exclusion criteria included multiplets, premature delivery, pregnancy complications, such as gestational diabetes mellitus, hypertension, and pre-eclampsia, and accompanied with other severe diseases. The basic information of the subjects was collected through medical record and questionnaires, and informed consents were obtained.

This research was in accord with the Helsinki Declaration, and was approved by Zhengzhou University Life Science Ethics Review Board (ZZUIRB 2021 – 139).

Grouping of the subjects

According to the standard of BMI for Asian adults [12], the maternal subjects were divided into three groups based on their pre-pregnant BMI: low weight (BMI<18.5), normal weight (18.5≤BMI<25.0), and overweight/ obese (BMI≥25.0). The case number of obese women was small in the study, thus the overweight and obese subjects were combined as overweight/ obese.

The levels of GWG recommended by Institute of Medicine guideline (IOM, 2009) are 12.5~18 kg, 11.5~16 kg, 7~11.5 kg, and 5~9 kg, for low weight, normal weight, overweight, and obese women of pre-pregnancy, respectively[13]. Based on the recommendation of IOM, the subjects were divided into low (below IOM guideline), normal (within the range of IOM guideline), and high (above IOM guideline) GWG groups.

The neonatal body size

The body measurements included BW, BL, and HC of the neonates. The newborns were weighted using electronic scale at the accuracy scale of 0.01 kg and measured for BL and HC using measuring tape at the accuracy of 0.1 cm. Ponderal Index (PI)[14] was calculated based on BW and BL, which is the index for estimating the nutrition condition of the neonates [PI = 100 × weight (g)/ length (cm) ^{3}].

Based on the BW and gestational age, the neonates were divided into three groups[15]: (1) Small for gestational age (SGA): BW below the 10th percentile for the corresponding gestational age; (2) Large for gestational age (LGA): BW above the 90th percentile for the corresponding gestational age; (3) Appropriate for gestational age (AGA): BW between the 10th and 90th percentile for the corresponding gestational age.

Measurement of adiponectin and leptin in umbilical cord blood

After fetal delivery, 10 ml of umbilical venous blood was drawn immediately before delivery of the placenta. Then the serum was separated after centrifuged at 3000 rpm for 10 min and stored at -80 °C for later tests. The serum levels of leptin and adiponectin were determined through Enzyme-linked immunoassay. The assays were conducted according to instructions using the ELISA kits (Shanghai Fusheng Industrial Co., Ltd. China).

After delivery, the placenta was weighed and its volume was estimated based on the formula. Placental volume (cm^3) = π/4 × long diameter (cm) × short diameter (cm) × thickness (cm) (placental surface was considered as oval like).

Statistical analysis

The database was established using EpiData 3.1 and the software of SPSS 21.0 was employed for data analysis. Continuous variables were expressed as mean ± SD ($\bar{x}$±s), and categorical variables were presented as frequencies and percentages. The chi-square test, *t*-test, analysis of variance, and bivariate correlation analysis were used to analyze the data. The significant level was set as α=0.05.

Results

General information of the subjects

A total of 546 mothers and their newborns were included in the study. The average age of the mothers was 29.5±4.4 years old, the means of pre-pregnancy BMI and GWG were 21.2±2.7 kg/m^2 and 17.2±4.9 kg, respectively. According to the pre-pregnancy BMI, 374 (68.5%) were in normal weight group, 89 (16.3%) and 83 (15.2%) were in low weight and overweight groups, respectively. Additionally, among the 546 pregnant women, 180 (33.0%) were in normal GWG, 50 (9.2%) were in low GWG, and 316 (57.9%) were in high GWG groups. The average BW, BL, and HC of neonates were 3.4±0.4 kg, 51.1±1.9 cm, and 34.8±1.2 cm, respectively. Among the 546 neonates, 25 were in SGA (4.6%), 356 were in AGA (65.2%) and 165 were in LGA (30.2%) groups respectively (Table 1).

	n (%)	$\bar{x}$±s
Mothers		
Age (y)		29.5±4.4
Educational Level		
Middle school or lower	53 (9.7)	
High school	110 (20.1)	
College and above	383 (70.1)	
Parity		
1	371 (67.9)	
≥2	175 (32.1)	
Delivery pattern		
Vaginal Delivery	244 (44.7)	
Cesarean Section	302 (55.3)	
Gestational weeks		39.3±1.2
Pre-pregnancy BMI (kg/m^2)		21.2±2.7
GWG (kg)		17.2±4.9
Pre-pregnancy BMI		
Low Weight	89 (16.3)	
Normal Weight	374 (68.5)	
Overweight/Obese	83 (15.2)	
GWG		
Low	50 (9.2)	
Normal	180 (33.0)	
High	316 (57.8)	
Newborns		
BW (kg)		3.4±0.4
BL (cm)		51.1±1.9
HC (cm)		34.8±1.2
SGA	25 (4.6)	
AGA	356 (65.2)	
LGA	165 (30.2)	

Note: BMI: body mass index; GWG: gestational weight gain; BW: birth weight; BL: body length; HC: head circumference; SGA: small for gestational age; AGA: appropriate for gestational age; LGA: large for gestational age.

Table 1: General information of the pregnant women and newborns (n=546)

Relationship between pre-pregnancy BMI and GWG

Noticeably, the highest GWG was in pre-pregnant normal weight group and the lowest GWG was in overweight group, but the differences among the three groups were not significant (*P*>0.05) (Table 2).

Pre-pregnancy BMI	n (%)	GWG (kg)
Low Weight	89 (16.3)	16.83±4.52
Normal Weight	374 (68.5)	17.50±4.89
Overweight/Obese	83 (15.2)	16.38±5.46
F		2.112
P		0.122

Note: BMI: body mass index; Low weight: pre-pregnancy BMI<18.5kg/m^2; Normal weight: 18.5kg/m^2≤pre-pregnancy BMI<25.0kg/m^2; Overweight/Obese: pre- pregnancy BMI≥25.0kg/m^2. GWG: gestational weight gain.

Table 2: Association of GWG with pre-pregnancy BMI ($\bar{x}$±s)

Effect of pre-pregnancy BMI on neonatal size

The frequency distribution of newborn birth weight was different among pregnant women with different pre-pregnant BMI (χ^2=17.625, *P*<0.01). Through pairwise comparison (α=0.05/3), the distribution of neonatal birth weight in low pre-pregnant weight group was distinctly different from normal weight and overweight groups (χ^2=11.224, *P*<0.01; χ^2=15.404, *P*<0.01). By further analysis, we found that the incidence of SGA in low pre-pregnant weight group was significantly higher, but the incidence of LGA was lower than that in pre-pregnancy normal and overweight groups (both *P*<0.05) (Table 3).

The effect of pre-pregnancy BMI on neonatal BW, BL, HC and PI was remarkable (*P*<0.01, *P*<0.05, *P*<0.05, *P*<0.05). By pairwise comparison, the average BW of neonates in pre-pregnant normal weight and overweight groups was significantly higher than that in low pre-pregnant weight group (both *P*<0.01), and the average BW in pre-pregnant overweight group was higher than that in normal weight group (*P*<0.05); Besides, the BL (*P*<0.05, *P*<0.01) and HC (both *P*<0.05) of neonates were higher in pre-pregnant normal and overweight groups than that in low weight group; Moreover, the neonatal PI were significantly higher in pre-pregnant overweight group than that in low weight group (*P*<0.05) (Table 3). Correlation analysis demonstrated that BW, BL, HC, and PI of neonates were positively correlated with pre-pregnant BMI (*P*<0.01, *P*<0.05, *P*<0.01, *P*<0.05).

To investigate whether GWG has the effect on the neonatal BW, BL, HC, and PI among women with different pre-pregnancy BMI levels, we studied the associations between BW, BL, HC, and PI and pre-pregnancy BMI in the low, normal, and high GWG groups. The results showed that in normal GWG group, the average BW and BL of neonates were significantly higher in normal than that in low pre-pregnant BMI group (*P*<0.05, *P*<0.05); In high GWG group, the PI was higher in overweight than that in low pre-pregnant BMI group. Moreover, in same GWG group, the BW, BL, HC, and PI of neonates had the trend being higher along with the increase of pre-pregnancy BMI, but the difference was not significant (*P*>0.05) (Table 4).

Pre-pregnancy BMI	n	SGA n(%)	AGA n(%)	LGA n(%)	BW (kg)	BL (cm)	HC (cm)	PI (g/cm^3)
Low Weight	89	8(9.0)	67 (75.3)	14(15.7)	3.2±0.5	50.7±2.1	34.5±1.24	2.5±0.2
Normal Weight	374	14(4.0)	244(65.0)	116(31.0)	3.4±0.4*	51.2±1.8*	34.8±1.2*	2.5±0.2
Overweight/Obese	83	3(3.6)	45(54.2)	35(42.2)	3.5±0.5$^{*\#}$	51.4±1.8*	35.0±1.1*	2.6±0.3*
χ^2/F			17.625		7.95	3.688	3.233	3.109
P			0.001		<0.001	0.026	0.040	0.045

Note: BMI: body mass index; Low weight: pre-pregnancy BMI<18.5kg/m^2; Normal weight: 18.5kg/m^2≤pre-pregnancy BMI<25.0kg/m^2; Overweight/Obese: pre-pregnancy BMI≥25.0kg/m^2; SGA: small for gestational age; AGA: appropriate for gestational age; LGA: large for gestational age. Compared with low weight group, **P*<0.05; Compared with normal weight group, $^\#$*P*<0.05.

Table 3: The distribution of neonatal body size in different pre-pregnancy BMI groups

GWG	pre-pregnancy BMI	n	BW (kg)	BL (cm)	HC (cm)	PI (g/cm^3)
Low						
	Low weight	11	3.1±0.4	49.7±2.5	34.0±1.1	2.5±0.2
	Normal weight	37	3.1±0.4	50.5±2.1	34.2±1.4	2.4±0.2
Normal						
	Low weight	46	3.1±0.5	50.2±1.6	34.3±1.3	2.5±0.2
	Normal weight	121	3.3±0.4*	50.8±1.8*	34.7±1.2	2.5±0.2
	Overweight/Obese	13	3.3±0.5	50.8±2.4	34.5±0.9	2.5±0.2
High						
	Low weight	32	3.4±0.4	51.7±2.2	34.9±1.1	2.5±0.2
	Normal weight	216	3.4±0.4	51.5±1.8	35.0±1.1	2.5±0.2
	Overweight/Obese	68	3.5±0.5	51.6±1.7	35.1±1.1	2.6±0.3*

Note: GWG: gestational weight gain; Low: GWG below IOM guideline; Normal: GWG within IOM guideline; High: GWG above IOM guideline; BMI: body mass index; Low weight: pre-pregnancy BMI<18.5kg/m^2; Normal weight: 18.5kg/m^2≤pre-pregnancy BMI<25.0kg/m^2; Overweight/Obese: pre-pregnancy BMI≥25.0kg/m^2; BW: birth weight; BL: body length; HC: head circumference; PI: Ponderal index; Compared with low weight group in same GWG group, $^*P$<0.05.

Table 4: Association of pre-pregnancy BMI with neonatal body size in different GWG groups (x±s)

Effect of GWG on neonatal physical development

The frequency distribution of newborn birth weight was different among different GWG groups (χ^2=36.274, P<0.01). Through pairwise comparison (α=0.05/3), the distribution of neonatal birth weight in high GWG was distinctly different from normal and low GWG groups (χ^2=18.629, P<0.01; χ^2=25.248, P<0.01). Further analysis showed that the incidence of LGA was higher in high GWG group than that in low and normal GWG groups (both P<0.05), and the incidence of SGA was lower than the other two groups (both P<0.05) (Table 5).

The BW, BL, HC, and PI of neonates were significantly different (P<0.01, P<0.01, P<0.01, P<0.05) in the three GWG groups. The average neonatal BW in normal and high GWG groups were significantly higher than that in low GWG group (P<0.05, P<0.01) and neonatal BW was notably higher in high GWG than that in normal GWG group (P<0.01). Besides, neonatal BL was significantly longer in high GWG group than that in low and normal GWG groups (both P<0.01). Neonatal HC was significantly larger in high and normal GWG groups than that in low GWG group (both P<0.01), and HC was significantly larger in high GWG than that in normal GWG group (P<0.01). Moreover, the neonatal PIs were significantly higher in normal and high GWG groups than that in low GWG group (P<0.05, P<0.01) (Table 5). The correlation analysis showed that the BW, BL, HC, and PI of neonates were positively correlated with GWG (all P<0.01).

GWG	n	SGA n(%)	AGA n(%)	LGA n(%)	BW (kg)	BL (cm)	HC (cm)	PI (g/cm^3)
Low	50	6(1.2)	40 (80.0)	4(8.0)	3.1±0.4	50.3±2.1	34.1±1.3	2.4±0.2
Normal	180	11(6.1)	131(72.8)	38(21.1)	3.3±0.4*	50.6±1.8	34.6±1.2*	2.5±0.2*
High	316	8(2.5)	185(58.5)	123(38.9)	3.5±0.4*#	51.5±1.8*#	35.0±1.1*#	2.5±0.2*
χ^2/F			36.274		22.089	18.043	15.41	3.696
P			<0.001		<0.001	<0.001	<0.001	0.025

Note: GWG: gestational weight gain; Low: GWG below IOM guideline; Normal: GWG within IOM guideline; High: GWG above IOM guideline; SGA: small for gestational age; AGA: appropriate for gestational age; LGA: large for gestational age. Compared with low GWG group, $^*P$<0.05; Compared with normal GWG group, $^\#P$<0.05.

Table 5: The distribution of neonatal body size in different GWG group

After adjusting pre-pregnancy BMI, in low pre-pregnant BMI group, the neonatal BW, BL, and HC were significantly higher in high GWG than that in low (P<0.05, P<0.01, P<0.05) and normal GWG groups (P<0.01, P<0.01, P<0.05). In addition, in normal pre-pregnant BMI group, neonatal BW, HC and PI were significantly higher in the normal GWG group than that in low GWG group (P<0.05, P<0.05, P<0.01), and the BW and BL were significantly higher in high GWG group than that in low (both P<0.01) and normal GWG group (both P<0.01), and the HC and PI of neonates were significantly higher in high GWG group than that in low GWG group (both P<0.01). Within the pre-pregnant overweight group, the BW, BL, HC, and PI of neonates in different GWG groups had no significant difference (P>0.05) (Table 6).

Pre-pregnancy BMI	GWG	n	BW (kg)	BL (cm)	HC (cm)	PI (g/cm^3)
Low weight						
	Low	11	3.1±0.4	49.7±2.5	34.0±1.1	2.5±0.2
	Normal	46	3.1±0.5	50.2±1.6	34.3±1.3	2.5±0.2
	High	32	3.4±0.4$^{*\#\#}$	51.7±2.2$^{**\#\#}$	34.9±1.1$^{*\#}$	2.5±0.2
Normal weight						
	Low	37	3.1±0.4	50.5±2.1	34.2±1.4	2.4±0.2
	Normal	121	3.3±0.4*	50.8±1.8	34.7±1.2*	2.5±0.2**
	High	216	3.4±0.4$^{**\#\#}$	51.5±1.8$^{**\#\#}$	35.0±1.1**	2.5±0.2**
Overweight/Obese						
	Normal	13	3.3±0.5	50.8±2.4	34.5±0.9	2.5±0.2
	High	68	3.5±0.5	51.59±1.7	35.08±1.1	2.6±0.3

Note: BMI: body mass index; Low weight: pre-pregnancy BMI<18.5kg/m^2; Normal weight: 18.5kg/m^2≤pre-pregnancy BMI<25.0kg/m^2; Overweight/Obese: pre- pregnancy BMI≥25.0kg/m^2; GWG: gestational weight gain; Low: GWG below IOM guideline; Normal: GWG within IOM guideline; High: GWG above IOM guideline; BW: birth weight; BL: body length; HC: head circumference; PI: Ponderal index; Compared with low GWG group, $^{*}P$<0.05, $^{**}P$<0.01. Compared with normal GWG group, $^{\#}P$<0.05, $^{\#\#}P$<0.01.

Table 6: Association of GWG with neonatal body size in different pre-pregnancy BMI groups ($\bar{x}$±s)

Comparison of leptin and adiponectin in umbilical cord blood of different pre-pregnancy BMI, GWG and neonatal birth-weight

The levels of leptin and adiponectin in cord blood were not significantly different among different Pre-pregnancy BMI groups (P>0.05), as well as different GWG groups (P>0.05) (Table 7).

The levels of leptin and adiponectin in umbilical cord blood were significantly different among different neonatal birth-weight groups (P<0.01). The serum level of leptin was higher in LGA group than that in SGA and AGA groups (P<0.05, P<0.01), and the level of adiponectin was higher in LGA group than that in AGA group (P<0.01) (Table 7).

Relationship between serum leptin, adiponectin of cord blood and neonatal body size

The levels of leptin and adiponectin in cord blood were positively correlated with neonatal BW, BL, HC, PI, Placental volume and Placental weight (P<0.05) (Table 8).

Groups		n	Leptin (μg/L)	*F*	*P*	Adiponectin (pg/ml)	*F*	*P*
Pre-pregnancy BMI								
	Low	21	14.2±6.0	0.461	0.631	2081.9±866.1	1.192	0.307
	Normal	106	13.5±4.2			1769.1±648.5		
	Overweight/Obese	37	12.8±4.1			1836.9±629.9		
GWG								
	Low	19	12.5±4.5	1.138	0.324	1766.3±676.9	0.160	0.853
	Normal	53	12.8±4.2			1851.9±634.1		
	High	92	13.8±4.5			1786.0±683.3		
Newborns								
	SGA	6	11.2±4.6	6.102	0.003	1539.9±488.4	5.096	0.007
	AGA	108	12.4±3.7			1696.6±605.2		
	LGA	50	14.9±5.1$^{*\#\#}$			2043.8±746.3$^{\#\#}$		

Note: BMI: body mass index; Low: pre-pregnancy BMI<18.5kg/m^2; Normal: 18.5kg/m^2≤ pre-pregnancy BMI<25.0kg/m^2; overweight/obese: pre-pregnancy BMI≥25.0kg/m^2. GWG: gestational weight gain; Low: GWG below IOM guideline; Normal: GWG within IOM guideline; High: GWG above IOM guideline. SGA: small for gestational age; AGA: appropriate for gestational age; LGA: large for gestational age. Compared with SGA group, $^{*}P$<0.05; Compared with AGA group, $^{\#\#}P$<0.05.

Table 7: Serum leptin and adiponectin levels of cord blood in different pre-pregnancy BMI, GWG and neonatal birth-weight groups ($\bar{x}$±s)

Indexes	BW (kg)		BL (cm)		HC (cm)		PI (g/cm^3)		PV (cm^3)		PW (g)	
	r	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Leptin (μg/L)	0.309	0.000	0.254	0.002	0.213	0.010	0.174	0.035	0.179	0.032	0.222	0.038
Adiponectin (pg/ml)	0.273	0.001	0.198	0.016	0.175	0.037	0.178	0.030	0.195	0.019	0.213	0.011

Note: BW: birth weight; BL: body length; HC: head circumference; PI: Ponderal index; PV: Placental volume; PW: Placental weight.

Table 8: Relationship between serum leptin, adiponectin of cord blood and neonatal body size

Discussion

Maintaining optimal GWG and pre-pregnancy BMI are essential for health and well-being of both mother and child. This study investigated the effects of GWG and pre-pregnant BMI on neonatal size. BW is a key index in evaluating neonatal health condition and predicting some adulthood chronic diseases, too low or too high BW could increase the risk of neonatal diseases [16-19].

In our study, the means of pre-pregnant BMI and GWG were 21.15±2.7 kg/m^2 and 17.22±4.93 kg, respectively. The percentages of pre-pregnant low weight and overweight were 16.3% and 15.2%, respectively, which are consistent with another study in China [20]. Women with low pre-pregnancy BMI are associated with an increased risk of preterm deliveries and having an SGA infant [21]. It is reported that infants at smaller birth size and born at SGA have higher incidences of neonatal morbidity and mortality than those normal birthweight ones [22]. In addition, pre-pregnancy overweight may increase the risk of adverse neonatal outcomes. The incidences of macrosomia and dystocia are increased along with the increase of pre-pregnant BMI [23]. Therefore, pre-pregnancy BMI is an important predictor of fetal growth. Our study showed that the percentages of low, normal, and high GWG were 9.2%, 33.0%, and 57.9% respectively, which means that more than half of the pregnant women gained more body weight than the recommended level, especially in the pre-pregnant normal and overweight groups, which is associated with some misleading information such as more food intake, especially high protein intake is good for pregnancy, might contribute to the over GWG [24,25]. There is an eminent need for the scientific and reasonable guidance of the pre-pregnancy BMI and GWG.

The present study showed that the incidences of SGA, AGA, and LGA were 4.6%, 65.2%, and 30.2% respectively, which is different from a cohort study[24], but similar to the MINA cohort study in Lebanon and Qatar [25]. The 4.6% proportion of SGA from our study was slightly lower than the 6.7% among MINA particiants in Lebanon and Qatar [25]. However, LGA was found in about 30.2% of infants which is slightly higher than that reported recently from the MINA cohort in Lebanon and Qatar (24.6%) [25]. Some reports indicated that the incidences of LGA and macrosomia are higher in obese women than that in normal weight ones [26-28]. In our study, the incidence of SGA was lower while the incidence of LGA was higher in pre-pregnant normal and overweight groups than that in pre-pregnant low weight group [29,30]. Moreover, the incidence of LGA was higher in high GWG group than that in low and nomal GWG group, while the incidence of SGA was higher in

low GWG group than that in the other groups, which is similar to other studies [20,31,32]. Excessive GWG and pre-pregnant overweight imply that pregnant women have more fat deposit and even have potential risk of dyslipidemia [33], which could result in increased energy flow to fetus through the placenta [34].

In present study, the average BW, BL, and HC of newborns were 3.4±0.4 kg, 51.1±1.9 cm, and 34.8±1.2 cm respectively, which were similar with other studies [25,35,36]. The three parameters plus PI were positively correlated with pre-pregnant BMI and GWG. In the other words, the BW, BL, HC, and PI of neonates are increased along with the increase of pre-pregnant BMI and GWG. These findings are in accord with with the reported study by Stamnes Koepp UM et al [37]. However, after the adjustment of GWG, the association of pre-pregnancy BMI with BW, BL, HC, and PI of neonates could not be seen, which implied that the effect of pre-pregnancy BMI on neonatal BW, BL, HC, and PI may not necessarily be involved with GWG or may be related to the small sample size of each group after stratification. Nevertheless, too low or high pre-pregnant BMI is not conducive to the health of mother and child. Women who are underweight or overweight and obese should try to achieve a healthy weight before pregnancy in order to have a better pregnancy outcome. After adjusting pre-pregnant BMI, the neonatal BW, BL, HC, and PI were increased along with GWG in low and normal pre-pregnant weight group, which indicates that the influence of GWG on BW, BL, HC, and PI is constant regardless of pre-pregnancy BMI. Nutritional plan should be personalized based on the pre-pregnancy BMI and the importance of appropriate GWG should be emphasized for the optimal fetal growth [38-40].

Leptin is a protein product expressed by obesity genes. As an intermediary molecule linking to fetal neuroendocrine system and adipose tissue, leptin participates in the regulation of fetal body mass growth throughout the gestational period, especially in the 2nd and 3rd trimesters [41]. Adiponectin is mainly secreted by adipocytes and plays important roles in the insulin sensitivity, anti-inflammation, anti-atherosclerosis, and maintenance of metabolism and energy balance. A study found that changes in serum adiponectin levels could reflect weight gain in the early period of newborns [42]. Our research found that the serum leptin and adiponectin levels in umbilical cord blood were not significantly different among different Pre-pregnancy BMI or GWG groups. Theoretically, substances with molecular weights of more than 500 Da could not pass through the placental barrier [43]. However, the molecular weights of leptin and adiponectin are 16 kDa and 30 kDa [44,45], respectively. Therefore, maternal serum leptin and adiponectin could not contribute to the leptin and adiponectin levels in the fetal circulation. Our study also found that the serum leptin and adiponectin levels in umbilical cord blood were higher in LGA group than that in SGA and AGA groups, and were significantly positively correlated with neonatal BW and Placental weight, which suggests that placenta and fetal adipose tissue, rather than maternal production, may be the main source of leptin and adiponectin production. This finding was consistent with the previous report [46,47]. Moreover, the significant correlation between the serum leptin and adiponectin levels in umbilical cord blood and the neonatal body size may imply that they can participate in the growth and development of fetuses.

Several limitations of this study should be addressed. First, the sample size is relative small and the results need to be further confirmed through large scale study or prospective cohort studies. Second, the study focused only the effect of pre-pregnancy BMI and GWG on BW, BL, HC, PI, Placental volume and Placental weight of neonates, without considering the effects of heredity and ethnicity.

Conclusion

In conclusion, the present study indicated that both pre-pregnancy BMI and GWG are positively associated with physical development of neonates. Pre-pregnant low weight strongly associates with the incidence of SGA, and excess GWG might increase the risk of LGA. Therefore, both pre-pregnant body weight and GWG should be considered for optimal physical development of neonates, which requires appropriate nutritional guide for child-bearing women. Moreover, the positive correlation between serum leptin and adiponectin of cord blood and neonatal physical development suggests that cord blood levels of leptin and adiponectin might be involved in the regulation of fetal growth and development.

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