Optimal gestational weight gain in Chinese pregnant women by Chinese-specific BMI categories: a multicentre prospective cohort study

Cai-Xia Zhang[1],†, Jian-Qiang Lai[2],†, Kai-Yan Liu[1], Nian-Hong Yang[3], Guo Zeng[4], Li-Mei Mao[5], Zeng-Ning Li[6], Yue Teng[7], Wei Xia[8], Nan Dai[9], Zhi-Xu Wang[10],* and Yi-Xiang Su[11],*

[1]Department of Epidemiology, School of Public Health, Sun Yat-sen University, Guangzhou, People's Republic of China: [2]National Institute for Nutrition and Health, Chinese Center for Disease Control and Prevention, Beijing, People's Republic of China: [3]Department of Nutrition and Food Hygiene, School of Public Health, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, People's Republic of China: [4]Department of Nutrition and Food Safety, West China School of Public Health and West China Fourth Hospital, Sichuan University, Chengdu, People's Republic of China: [5]Department of Nutrition and Food Hygiene, School of Public Health, Southern Medical University, Guangzhou, People's Republic of China: [6]Department of Clinical Nutrition, Hebei Medical University First Affiliated Hospital, Shijiazhuang, People's Republic of China: [7]Outpatient of Nutrition Consult, Beijing Haidian District Maternal and Child Health Hospital, Beijing, People's Republic of China: [8]Department of Children's and Adolescent Health, Public Health College of Harbin Medical University, Harbin, People's Republic of China: [9]Department of Obstetrics and Gynecology, Danyang People's Hospital of Jiangsu Province, Danyang, People's Republic of China: [10]Department of Maternal, Child and Adolescent Health, School of Public Health, Nanjing Medical University, Nanjing 211166, People's Republic of China: [11]Department of Nutrition, School of Public Health, Sun Yat-sen University, Guangzhou 510080, People's Republic of China

Abstract

Objective: To establish optimal gestational weight gain (GWG) in Chinese pregnant women by Chinese-specific BMI categories and compare the new recommendations with the Institute of Medicine (IOM) 2009 guidelines.
Design: Multicentre, prospective cohort study. Unconditional logistic regression analysis was used to evaluate the OR, 95 % CI and the predicted probabilities of adverse pregnancy outcomes. The optimal GWG range was defined as the range that did not exceed a 1 % increase from the lowest predicted probability in each pre-pregnancy BMI group.
Setting: From nine cities in mainland China.
Participants: A total of 3731 women with singleton pregnancy were recruited from April 2013 to December 2014.
Results: The optimal GWG (ranges) by Chinese-specific BMI was 15·0 (12·8–17·1), 14·2 (12·1–16·4) and 12·6 (10·4–14·9) kg for underweight, normal weight and overweight pregnant women, respectively. Inappropriate GWG was associated with several adverse pregnancy outcomes. Compared with women gaining weight within our proposed recommendations, women with excessive GWG had higher risk for macrosomia, large for gestational age and caesarean section, whereas those with inadequate GWG had higher risk for low birth weight, small for gestational age and preterm delivery. The comparison between our proposed recommendations and IOM 2009 guidelines showed that our recommendations were comparable with the IOM 2009 guidelines and could well predict the risk of several adverse pregnancy outcomes.
Conclusions: Inappropriate GWG was associated with higher risk of several adverse pregnancy outcomes. Optimal GWG recommendations proposed in the present study could be applied to Chinese pregnant women.

†These authors contributed equally to this work.

Corresponding authors: Email suyx@mail.sysu.edu.cn; zhixu.wang@126.com

Gestational weight gain (GWG) has been reported to be essential for pregnancy outcomes. Excessive GWG increases the risks of maternal and neonatal complications, including gestational diabetes mellitus (GDM), hypertensive disorders, caesarean section, post-partum weight retention, macrosomia, large for gestational age (LGA) infants and offspring overweight/obesity[1–5]. Inadequate GWG is linked with increased risks of small for gestational age (SGA) newborns, low birth weight (LBW) infants, preterm delivery and failure to initiate breast-feeding[1,4].

In recent years, there are an increasing number of overweight and obesity in China and other developing Asian countries[6]. The prevalence of overweight[7,8] and obesity[9,10] among Chinese reproductive-aged women was 10–24 % and 2·6–9·2 %, respectively. On the other hand, almost 9·0 % women in China were underweight, whereas it was only 2·0 % in the USA[11]. Evidence has shown that women with higher pre-pregnancy BMI were more likely to have a series of adverse maternal and neonatal outcomes, such as macrosomia, LGA, caesarean section, GDM and gestational hypertension[12–17]. In contrast, pregnant women with lower BMI were at increased risk for LBW, SGA, intrauterine growth-restricted infants and preterm delivery[12,13,17].

So far, there is no international consensus on the recommendation about GWG. The United States Institute of Medicine (IOM) revised new GWG guidelines according to the WHO BMI categories in 2009, considering the incidences and risks of several potential outcomes such as fetal growth, preterm birth, caesarean section, and maternal and offspring obesity[18]. Due to the lack of official GWG recommendation for Chinese pregnant women, IOM 2009 GWG guideline was also used in China[19]. However, the IOM guidelines are based mainly on Caucasian women, which may limit its generalisability to other populations. Moreover, the WHO BMI criterion may not be directly applicable to the Chinese populations, owing to racial difference in body composition and dietary habits between Chinese and Western populations. It has been reported that Asian women were more likely to have a lower BMI and a smaller GWG than those in Europe and North America[20]. Given the variations in race ethnicity, diet and other factors between Chinese and Western populations, the appropriateness of using the IOM 2009 GWG recommendations for Chinese women should be examined.

Studies conducted in Hong Kong[21] and New York[22] calculated proper GWG among pregnant women with good pregnancy outcomes. More studies conducted in different countries and regions[23–32] suggested optimal GWG with the lowest risk of various adverse pregnancy outcomes. However, to date, no study has been reported in China to create the optimal GWG considering multiple maternal and neonatal outcomes. Therefore, the purpose of this multicentre prospective study is to create the optimal GWG using a quantitative approach to estimate the total predicted probability of the composite maternal and neonatal outcomes. We aimed to define GWG ranges for Chinese women according to Chinese-specific BMI classification and to examine whether the proposed GWG ranges can improve pregnancy outcomes in comparison with IOM 2009 GWG guidelines.

## Materials and methods

Study populations

This prospective study was conducted at hospitals of nine cities in mainland China, including Beijing, Wuhan, Chengdu, Shenzhen, Dongguan, Harbin, Shijiazhuang, Qingdao and Danyang, from April 2013 to December 2014. Pregnant women were considered eligible if they had regular prenatal care till delivery and maintained complete data during the study period. Inclusion criteria were as follows: women with Chinese nationality, aged 20–35 years, had a living singleton pregnancy and < 12 weeks pregnant. The subjects were excluded if they had a situation with pre-existing diabetes mellitus or hypertension, endocrine disease and other complications. Women with multiple pregnancy or with insufficient information about their height, pre-pregnancy weight and gestational weight were also excluded. A total of 3806 women were recruited. Due to the extreme small number of obese women (n 75), we restricted our analysis to underweight (n 821), normal weight (n 2503) and overweight women (n 407). Consequently, a total of 3731 women were included for the analysis (Fig. 1).

Data collection

The baseline data were collected by trained interviewers through face-to-face interviews. A structured questionnaire was used to collect information on socio-demographic characteristics (e.g., maternal age, educational level, occupation and family income), pre-pregnancy body weight and self-reported height, lifestyle (e.g., regular and passive smoking, alcohol drinking, insomnia and physical activity), menstrual and reproductive history and history of diseases. Information on physical activity was obtained by asking subjects about their exercise frequency and classified as never, occasionally, sometimes and frequently. Insomnia disorder was defined as difficulties in initiating or maintaining sleep.

Anthropometric measurement

The trained staffs measured the participant's weight with uniform standards at the first prenatal visit, the 12th gestational week, the 28th gestational week and prior to delivery. Pre-pregnancy BMI (kg/m^2) was calculated by dividing self-reported pre-pregnancy weight in kg by the square of the height in metres. According to the 'Guidelines for prevention and control of overweight and obesity in China'[33], maternal pre-pregnancy BMI was
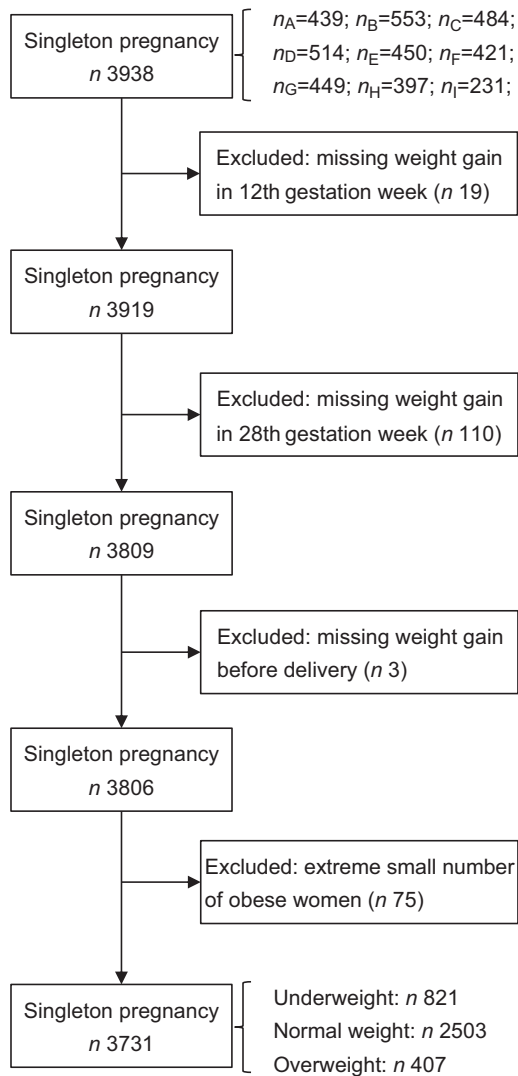
Fig. 1 Study cohort flow chart. Letters A–I represented nine cities in mainland China (A, Beijing; B, Shijiazhuang; C, Chengdu; D, Wuhan; E, Dongguan; F, Shenzhen; G, Harbin; H, Danyang; I, Qingdao)

categorised as underweight (<18.5 kg/m^2), normal weight (18.5–23.9 kg/m^2), overweight (24.0–27.9 kg/m^2) and obesity (≥ 28.0 kg/m^2). Maternal GWG was calculated by subtracting the maternal pre-pregnancy weight from the last measured weight prior to delivery.

Outcomes of interest

Information on maternal outcomes (including gestational hypertension, GDM and mode of delivery) and the neonatal outcomes (including birth weight and gestational age at delivery) was obtained from the medical records. Gestational age was determined from last menstrual period which was defined by ultrasound assessments. Preterm delivery was defined as delivery occurring before 37 completed weeks of gestation[34]. Neonates with their birth weight < 2500 g, between 2500 and 4000 g, equal to or greater than 4000 g were classified as LBW, normal birth weight and macrosomia, respectively[35]. SGA and LGA neonates were defined as birth weights below the 10th percentile for gestational age and above the 90th percentile, respectively[36]. Gestational hypertension was diagnosed when the pregnant woman had a blood pressure $> 140/90$ mmHg after 20th gestational week[37]. GDM was diagnosed using the International Association of Diabetes in Pregnancy Study Groups criteria[38]. The diagnosis of GDM was made when any of the following plasma glucose values are exceeded: fasting blood glucose ≥ 5.1 mmol/l, plasma glucose levels at 60 min ≥ 10.0 mmol/l or at 120 min ≥ 8.5 mmol/l following a 75 g oral glucose tolerance test at 24–28 gestational weeks. The mode of delivery was categorised as caesarean section and vaginal delivery.

Statistical analysis

The comparisons of characteristics among subjects were conducted based on pre-pregnancy BMI groups. Continuous variables were expressed as mean values and standard deviations and evaluated using ANOVA test. Categorical variables were expressed as numbers (%, percentage) and evaluated by χ^2 test.

Macrosomia, LBW, LGA, SGA, preterm delivery, caesarean section, GDM and gestational hypertension were chosen as the important pregnancy outcomes which are known to be affected by GWG. Logistic regression models were used to obtain the predicted probabilities[25] of the pregnancy outcomes relating to GWG in different pre-pregnancy BMI groups. The total predicted probabilities in different BMI groups were estimated by combining the predicted probabilities of pregnancy outcomes. To determine the optimal GWG value in different pre-pregnancy BMI groups, quadratic function model was used to improve the fitness of the relationship between GWG and the total predicted probability, as reported by a previous study[24]. The optimal GWG range was defined as the range that did not exceed a 1 % increase from the lowest predicted probability[24].

The IOM 2009 GWG guidelines recommended 12.5–18 kg for underweight (pre-pregnancy BMI < 18.5 kg/m^2), 11.5–16.0 kg for normal weight (pre-pregnancy BMI 18.5–24.9 kg/m^2), 7.0–11.5 kg for overweight (pre-pregnancy BMI 25–29.9 kg/m^2) and 5–9.1 kg for obese (pre-pregnancy BMI ≥ 30.0 kg/m^2) pregnant women classified by WHO BMI categories[39]. According to the IOM 2009 GWG guidelines and our proposed recommendations, excessive GWG group was defined as GWG above the upper range of the recommendations, whereas inadequate GWG group was defined as GWG below the lower range of the recommendations. All other women were classified as having adequate GWG.

OR and 95 % CI of the associations between pre-pregnancy BMI groups, GWG groups and pregnancy outcomes were calculated using multivariable unconditional logistic regression models. Confounding factors, selected based on the literatures and the comparison between pre-pregnancy BMI groups, included maternal age (continuous), parity (primiparous or multiparous), gestational age of delivery (for macrosomia and LBW), family history of diabetes (for GDM) or family history of hypertension (for gestational hypertension). Moreover, the comparison between the association of pregnancy outcomes with GWG categorised by our proposed recommendations and IOM 2009 GWG guidelines was performed using logistic analyses. Women with adequate GWG judged by our proposed recommendations or IOM 2009 GWG guidelines were separately served as the reference group. Positive and negative predictive values, sensitivity, specificity and AUC for detecting adverse pregnancy outcomes were calculated for our proposed recommendations and IOM 2009 GWG guidelines.

All P values are two sided, and P values of <0·05 were considered as statistically significant. Statistical analyses were performed using SPSS 25.0.

Results

The maternal and neonatal characteristics in different pre-pregnancy BMI groups are shown in Table 1. The majority of pregnant women had a normal weight (67·1 %), 22·0 % were underweight and 10·9 % were overweight. Overweight women had less GWG than underweight and normal weight women. More overweight women had a family history of diabetes or hypertension than underweight women. The proportion of primiparous women decreased with higher pre-pregnancy BMI. The prevalence of gestational hypertension, GDM, caesarean section, LGA and macrosomia increased with higher pre-pregnancy BMI. The prevalence of SGA decreased with increasing pre-pregnancy BMI. No significant differences were observed between the three groups in terms of educational level, occupation, family income, alcohol drinking, active and passive smoking, insomnia situation, physical activity and LBW ($P > 0·05$).

The association between pre-pregnancy BMI and maternal and neonatal outcomes is shown in Table 2. Compared with normal weight women, overweight women had an increased risk of macrosomia, LGA, preterm delivery, caesarean section, GDM and gestational hypertension, with adjusted OR of 2·07 (95 % CI 1·51, 2·84), 1·77 (95 % CI 1·34, 2·35), 1·92 (95 % CI 1·22, 3·03), 1·36 (95 % CI 1·10, 1·69), 1·40 (95 % CI 1·05, 1·88) and 1·87 (95 % CI 1·10, 3·17), respectively. By contrast, underweight women had a significantly lower risk of macrosomia (OR 0·46; 95 % CI 0·31, 0·68), LGA (OR 0·53; 95 % CI 0·38, 0·73), caesarean section (OR 0·79; 95 % CI 0·67, 0·93)

and GDM (OR 0·72; 95 % CI 0·54, 0·96) compared with normal weight women.

Figure 2 shows the associations between GWG and predicted probability of maternal and neonatal outcomes in different pre-pregnancy BMI groups. Higher GWG was associated with a lower risk of LBW, SGA, preterm delivery and GDM, whereas higher GWG was associated with a higher risk of macrosomia, LGA, caesarean section and gestational hypertension.

The total predicted probability of composite maternal and neonatal outcomes in relation to GWG in quadratic function model stratified by pre-pregnancy BMI categories is shown in Table 3 and Fig. 3. The predicted probability of composite adverse outcomes showed a U-shaped curve with increasing GWG for all BMI groups. The total predicted probability of composite adverse outcomes was lowest at 15·0, 14·2 and 12·6 kg, which were defined as optimal GWG values for underweight, normal weight and overweight women, respectively. The optimal GWG ranges, defined as an increased risk < 1 % compared with optimal GWG, were 12·8–17·1 kg for underweight pregnant women, 12·1–16·4 kg for normal weight pregnant women and 10·4–14·9 kg for overweight pregnant women, respectively.

Table 4 shows the results of the associations between multiple maternal and neonatal outcomes and GWG categorised based on our proposed recommendations and IOM 2009 GWG guidelines. Compared with pregnant women with adequate GWG judged by our proposed recommendations, excessive GWG was positively associated with the risk of macrosomia, LGA and caesarean section, with OR of 2·44 (95 % CI 1·82, 3·27), 2·04 (95 % CI 1·60, 2·62) and 1·43 (95 % CI 1·24, 1·66), respectively, whereas inadequate GWG was associated with higher risks for LBW, SGA and preterm delivery, with OR of 2·66 (95 % CI 1·34, 5·26), 2·02 (95 % CI 1·40, 2·93) and 1·56 (95 % CI 1·04, 2·34), respectively. The corresponding OR in comparison with pregnant women with adequate GWG judged by the IOM 2009 GWG guidelines were 2·63 (95 % CI 1·93, 3·60) for macrosomia, 2·26 (95 % CI 1·74, 2·93) for LGA, 1·35 (95 % CI 1·17, 1·56) for caesarean section, 2·64 (95 % CI 1·31, 5·33) for LBW, 2·03 (95 % CI 1·38, 2·96) for SGA and 1·61 (95 % CI 1·02, 2·53) for preterm delivery, respectively.

Our proposed recommendations exhibited similar predictive values for adverse pregnancy outcomes to those of the IOM 2009 GWG guidelines. All of the AUC values of different pregnancy outcomes predicted by our cut-off value were > 0·50 (AUC ranged from 0·542 to 0·635, all $P < 0·05$) (Table 5).

Discussion

The current study examined the proper GWG for each pre-pregnancy BMI category according to Chinese-specific BMI

Table 1 Characteristics of the studied population according to Chinese-specific BMI categories (*n* 3731)

	Pre-pregnancy BMI classification (kg/m²)						
	Underweight <18·5		Normal weight 18·5–23·9		Overweight 24·0–27·9		
Variables	*n*	%	*n*	%	*n*	%	*P**
No. of subjects	821	22·0	2503	67·1	407	10·9	
Age (years)							0·002
Mean	27·0		28·0		28·8		
SD	3·0		3·2		3·4		
Pre-pregnancy BMI (kg/m²)							<0·001
Mean	17·5		20·8		25·4		
SD	0·8		1·4		1·0		
GWG (total) (kg)							0·001
Mean	16·9		16·5		15·1		
SD	4·4		4·7		5·2		
Gestational week at delivery							0·019
Mean	39·1		39·1		38·9		
SD	1·3		1·3		1·5		
Birth weight (g)							<0·001
Mean	3·3		3·4		3·5		
SD	0·4		0·4		0·5		
Occupation							0·050
Administrative staff	24	2·9	77	3·1	10	2·5	
Blue-collar workers	553	67·4	1786	71·4	270	66·3	
Peasants/others	244	29·7	640	25·6	127	31·2	
Education level							0·427
Elementary school/less	4	0·5	6	0·2	0		
Middle school	41	5·0	152	6·1	27	6·6	
High school	133	16·2	379	15·1	67	16·5	
Junior college	280	34·1	802	32·0	141	34·6	
College or above	363	44·2	1164	46·5	172	42·3	
Family income (Yuan)							0·631
≤1000	3	0·4	16	0·6	1	0·2	
1001–2999	100	12·2	335	13·4	58	14·3	
3000–4999	280	34·1	839	33·5	141	34·6	
5000–9999	291	35·4	914	36·5	151	37·1	
≥10 000	147	17·9	399	15·9	56	13·8	
Parity							0·011
0	563	68·6	1640	65·5	244	60·0	
≥1	258	31·4	863	34·5	163	40·0	
Alcohol drinking	12	1·5	28	1·1	6	1·5	0·665
Active smoking	18	2·2	41	1·6	9	2·2	0·485
Passive smoking	269	32·8	757	30·2	135	33·2	0·255
Insomnia	42	5·1	116	4·6	21	5·2	0·801
Physical activity	119	14·5	414	16·5	74	18·2	0·210
Family history of diabetes	76	9·3	307	12·3	75	18·4	<0·001
Family history of hypertension	187	23·3	680	27·6	153	38·7	<0·001
Macrosomia (≥ 4000 g)	32	3·9	212	8·5	62	15·2	<0·001
Low birth weight (≤ 2500 g)	19	2·3	45	1·8	9	2·2	0·602
Large for gestational age	47	5·7	274	10·9	76	18·7	<0·001
Small for gestational age	55	6·7	122	4·9	14	3·4	0·032
Preterm delivery	23	2·8	83	3·3	26	6·4	0·003
Caesarean section	329	40·1	1183	47·3	226	55·5	<0·001
Gestational diabetes	65	7·9	295	11·8	69	17·0	<0·001
Gestational hypertension	14	1·7	58	2·3	20	4·9	0·002

GWG, gestational weight gain.
*Continuous variables were evaluated using ANOVA test and categorical variables were evaluated by χ^2 test.

classification. The results showed that inappropriate GWG was associated with higher risk of several maternal and neonatal outcomes. The optimal GWG (ranges) proposed in the present study was 15·0 kg (12·8–17·1) for underweight pregnant women, 14·2 kg (12·1–16·4) for normal weight pregnant women and 12·6 kg (10·4–14·9) for overweight pregnant women. The comparison between our proposed recommendations and IOM 2009 GWG guidelines showed that these two recommendations were comparable in predicting adverse pregnancy outcomes.

The distribution of pre-pregnancy BMI categories in the present study was consistent with the result of another multicentre study, with 18·9 % in the underweight and 11·1 % in the overweight, respectively[9]. Pre-pregnancy BMI was an independent predictor of pregnancy outcomes. In accordance with most of the previous studies[12–16], our study

Table 2 OR and 95 % CI of the association between pre-pregnancy BMI and maternal and neonatal outcomes (*n* 3731)

| Pregnancy outcomes		Underweight		Normal weight	Overweight		P_{trend}
		OR	95 % CI		OR	95 % CI	
Macrosomia	No. of cases	32		212	62		
	Crude OR	0·44	0·30, 0·64	1·00	1·94	1·43, 2·63	<0·001
	Adjusted OR*	0·46	0·31, 0·68	1·00	2·07	1·51, 2·84	<0·001
LBW	No. of cases	19		45	9		
	Crude OR	1·29	0·75, 2·23	1·00	1·24	0·60, 2·55	0·690
	Adjusted OR*	1·32	0·70, 2·46	1·00	0·62	0·26, 1·51	0·143
LGA	No. of cases	47		274	76		
	Crude OR	0·49	0·36, 0·68	1·00	1·87	1·41, 2·47	<0·001
	Adjusted OR†	0·53	0·38, 0·73	1·00	1·77	1·34, 2·35	<0·001
SGA	No. of cases	55		122	14		
	Crude OR	1·40	1·01, 1·95	1·00	0·70	0·40, 1·22	0·009
	Adjusted OR†	1·35	0·97, 1·88	1·00	0·72	0·41, 1·27	0·022
Preterm delivery	No. of cases	23		83	26		
	Crude OR	0·84	0·53, 1·34	1·00	1·99	1·26, 3·13	0·005
	Adjusted OR†	0·88	0·55, 1·41	1·00	1·92	1·22, 3·03	0·013
Caesarean section	No. of cases	329		1183	226		
	Crude OR	0·75	0·64, 0·88	1·00	1·43	1·16, 1·77	<0·001
	Adjusted OR†	0·79	0·67, 0·93	1·00	1·36	1·10, 1·69	<0·001
GDM	No. of cases	65		295	69		
	Crude OR	0·64	0·49, 0·85	1·00	1·53	1·15, 2·03	<0·001
	Adjusted OR‡	0·72	0·54, 0·96	1·00	1·40	1·05, 1·88	<0·001
Gestational hypertension	No. of cases	14		58	20		
	Crude OR	0·73	0·41, 1·32	1·00	2·18	1·30, 3·66	0·002
	Adjusted OR§	0·85	0·47, 1·55	1·00	1·87	1·10, 3·17	0·030

LBW, low birth weight; LGA, large for gestational age; SGA, small for gestational age; GDM, gestational diabetes mellitus.
*Adjusted for maternal age, parity and gestational age.
†Adjusted for maternal age and parity.
‡Adjusted for maternal age, parity and family history of diabetes.
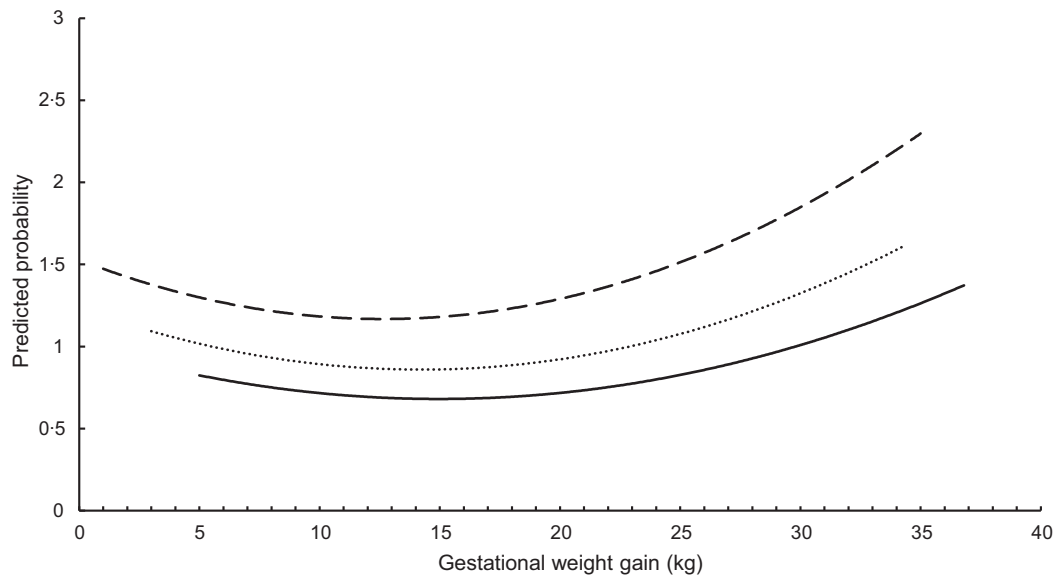§Adjusted for maternal age, parity and family history of hypertension.
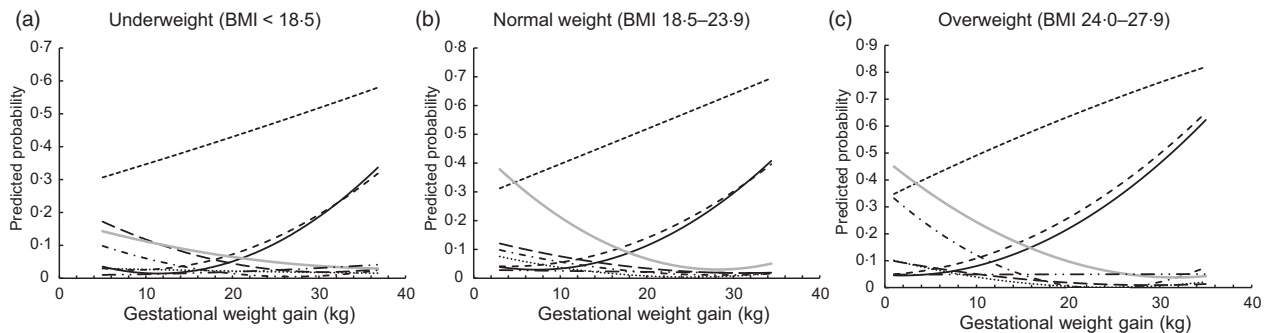
Fig. 2 Predicted probabilities of macrosomia (——), low birth weight (⋯⋯), preterm delivery (-·-·), small for gestational age (– –), large for gestational age (- - -), caesarean section (-----), gestational diabetes mellitus (——) and gestational hypertension (–···) with increasing gestational weight gain, stratified by pre-pregnancy BMI (underweight, *n* 821; normal weight, *n* 2503; overweight, *n* 407)

Table 3 The quadratic function models and the optimal GWG corresponding to the lowest total predicted probability of combining adverse pregnancy outcomes, according to pre-pregnancy Chinese-specific BMI categories

BMI category	R^2	Quadratic function model	Optimal GWG (kg)*	
Underweight	0·998	$Y = 0.0015x^2 - 0.0432x + 1.005$	15·0	12·8–17·1
Normal weight	0·999	$Y = 0.0019x^2 - 0.0529x + 1.235$	14·2	12·1–16·4
Overweight	0·980	$Y = 0.0023x^2 - 0.0571x + 1.528$	12·6	10·4–14·9

GWG, gestational weight gain; *Y*, total predicted probability; *x*, GWG.
*The lower and upper margins of the GWG range represented that total predicted risk of composite adverse outcomes (macrosomia, LBW, LGA, SGA, preterm delivery, caesarean section, GDM and gestational hypertension) did not exceed a 1 % increase from the lowest total predicted probability.

Fig. 3 Total predicted probability of adverse pregnancy outcomes (including gestational hypertension, gestational diabetes mellitus, caesarean section, macrosomia, low birth weight, preterm delivery, small for gestational age and large for gestational age) by gestational weight gain, stratified by pre-pregnancy BMI (——, underweight, *n* 821, BMI < 18·5; ·······, normal weight, *n* 2503, BMI 18·5–23·9; – –, overweight, *n* 407, BMI 24·0–27·9)

showed that a significantly higher proportion of overweight women experienced adverse maternal and neonatal outcomes, such as macrosomia, LGA, caesarean section, GDM and gestational hypertension, whereas the risk of SGA decreased with increasing pre-pregnancy BMI. No significant difference was noted in the risk of LBW in relation to pre-pregnancy BMI. This might be due to the small proportion of LBW in the subgroup population.

The GWG recommendations varied by national origin. One study including 2702 Korean women reported that the optimal GWG was considerably higher and wider than recommended by IOM 2009 GWG[28]. However, the optimal GWG among Japanese pregnant women was narrower than that of the IOM 2009 GWG[24]. In the present study, the suggested GWG defined for underweight and normal weight women was generally similar to IOM 2009 GWG guidelines, although it was a little narrower than that of the IOM 2009 guidelines. However, the suggested GWG defined for overweight women was considerably higher than that of the IOM 2009 GWG guidelines. In the current study, we could not determine the appropriate GWG for obese women due to the small sample size. The intrinsic ethnic, population and regional differences among Chinese women and other populations might have a potential effect on the weight gain profile.

So far, no consensus has been reached on the method of defining optimal GWG among pregnant women. Optimal GWG has been examined in some epidemiological studies, of which varied in statistical methods, selected adverse maternal and infant outcomes[22,25,26,31,40–43]. Recommendations made in Hong Kong[21] and New York[22]

were derived from women with good pregnancy outcomes. However, this might be not reliable for the general population owing to the exclusion of women and infants with any adverse pregnancy outcome. Some studies[25,26,32,39,44] highlighted the importance of fetal growth to determine the GWG. But more studies[24,27–29,45] emphasised the importance of both maternal and neonatal pregnancy outcomes. The IOM 2009 GWG guidelines were established according to the lowest prevalence of the commonly pregnancy outcomes from various large studies[18]. A meta-analysis of twenty-five cohort studies from Europe and North America examined optimal GWG ranges with consideration of composite adverse outcomes like preeclampsia, gestational hypertension, gestational diabetes, caesarean delivery, preterm birth, SGA and LGA[45]. In the present study, a quantitative approach was used to estimate the total predicted probability of the composite maternal and neonatal outcomes, including macrosomia, LBW, LGA, SGA, preterm delivery, caesarean section, GDM and gestational hypertension.

It has been suggested that different countries need to have their own BMI classification criteria based on their own morbidity and mortality data[46]. Previous studies creating GWG are based on different pre-pregnancy BMI. The IOM 2009 GWG guidelines used WHO BMI categories to classify pregnant women to underweight (BMI < 18·5), normal weight (18·5 ≤ BMI < 24·9), overweight (25·0 ≤ BMI < 29·9) and obese (BMI ≥ 30·0) women. The pre-pregnancy BMI used in the Korean population was classified according to Asia-specific standards from the WHO as follows: underweight (BMI < 18·5), normal weight (18·5 ≤ BMI < 23), overweight (23 ≤ BMI < 25)

Table 4 Comparison between the association of pregnancy outcomes with GWG categorised by our proposed recommendations and IOM 2009 GWG guidelines (*n* 3731)

| | | Our proposed GWG categories | | | | | | IOM 2009 GWG categories | | | | | |
| | | Inadequate | | Adequate | Excessive | | P_{trend} | Inadequate | | Adequate | Excessive | | P_{trend} |
Pregnancy outcome		OR	95 % CI		OR	95 % CI		OR	95 % CI		OR	95 % CI	
Macrosomia	No. of cases	27		65	214			14		53	239		
	Adjusted OR*	0·76	0·48, 1·22	1·00	2·44	1·82, 3·27	<0·001	0·62	0·34, 1·14	1·00	2·63	1·93, 3·60	<0·001
LBW	No. of cases	29		20	24			25		20	28		
	Adjusted OR*	2·66	1·34, 5·26	1·00	1·58	0·80, 3·12	0·222	2·64	1·31, 5·33	1·00	1·35	0·70, 2·61	0·445
LGA	No. of cases	42		100	255			26		81	290		
	Adjusted OR†	0·74	0·50, 1·07	1·00	2·04	1·60, 2·62	<0·001	0·72	0·45, 1·13	1·00	2·26	1·74, 2·93	<0·001
SGA	No. of cases	61		62	68			52		64	75		
	Adjusted OR†	2·02	1·40, 2·93	1·00	0·76	0·54, 1·09	0·082	2·03	1·38, 2·96	1·00	0·75	0·53, 1·06	0·056
Preterm delivery	No. of cases	45		55	32			33		49	50		
	Adjusted OR†	1·56	1·04, 2·34	1·00	0·41	0·26, 0·63	<0·001	1·61	1·02, 2·53	1·00	0·57	0·38, 0·85	0·004
Caesarean section	No. of cases	284		547	907			214		521	1003		
	Adjusted OR†	0·94	0·78, 1·14	1·00	1·43	1·24, 1·66	<0·001	0·91	0·73, 1·12	1·00	1·35	1·17, 1·56	<0·001
GDM	No. of cases	137		158	134			111		159	159		
	Adjusted OR‡	1·74	1·34, 2·24	1·00	0·60	0·47, 0·76	<0·001	1·77	1·35, 2·33	1·00	0·54	0·43, 0·69	<0·001
Gestational hypertension	No. of cases	18		29	45			14		30	48		
	Adjusted OR§	1·06	0·58, 1·94	1·00	1·13	0·67, 1·69	0·618	1·02	0·54, 1·96	1·00	0·88	0·55, 1·41	0·577

LBW, low birth weight; LGA, large for gestational age infant; SGA, small for gestational age infant; GDM, gestational diabetes mellitus.
*Adjusted for maternal age, parity, gestational age and pre-pregnancy BMI.
†Adjusted for maternal age, parity and pre-pregnancy BMI.
‡Adjusted for maternal age, parity, family history of diabetes and pre-pregnancy BMI.
§Adjusted for maternal age, parity, family history of hypertension and pre-pregnancy BMI.

Table 5 Predictive values of our proposed recommendations and IOM guidelines for the adverse pregnancy outcomes

Pregnancy outcomes		PPV	NPV	Sensitivity	Specificity	AUC	*P*
Macrosomia	Our recommendations	12·0	95·3	69·9	54·1	0·620	<0·001
	IOM guidelines	12·0	96·2	78·1	48·9	0·635	<0·001
LBW	Our recommendations	1·6	97·8	27·4	65·7	0·611	0·001
	IOM guidelines	1·6	97·9	27·4	67·2	0·603	0·002
LGA	Our recommendations	14·3	92·7	64·2	54·1	0·592	<0·001
	IOM guidelines	14·6	93·9	73·0	49·0	0·610	<0·001
SGA	Our recommendations	4·9	94·8	32·5	65·8	0·573	<0·001
	IOM guidelines	5·2	94·9	33·5	67·3	0·570	<0·001
Preterm delivery	Our recommendations	4·3	96·9	41·7	66·1	0·583	0·001
	IOM guidelines	4·0	96·7	37·1	67·5	0·557	0·026
Caesarean section	Our recommendations	51·3	57·1	52·2	56·2	0·542	<0·001
	IOM guidelines	50·9	57·6	57·7	50·7	0·542	<0·001
GDM	Our recommendations	7·5	84·8	31·2	50·0	0·594	<0·001
	IOM guidelines	8·0	84·5	37·1	44·6	0·592	<0·001
Gestational hypertension	Our recommendations	2·5	97·6	48·9	52·2	0·505	0·861
	IOM guidelines	2·4	97·5	52·2	46·7	0·506	0·848

IOM, Institute of Medicine; PPV, positive predictive value; NPV, negative predictive value; LBW, low birth weight; LGA, large for gestational age infant; SGA, small for gestational age infant; GDM, gestational diabetes mellitus.

and obese women (BMI ≥ 25)[28]. One study in Japan was based on five pre-pregnancy BMI subgroups (17·0–18·4, 18·5–19·9, 20–22·9, 23–24·9 and 25–27·4 kg/m²)[24]. Another study also conducted in Japan creating optimal GWG only included overweight and obese pregnant women with a BMI ≥ 25 kg/m²[23]. Recent research claimed that Chinese people have an elevated risk for obesity-related diseases at a lower BMI than Caucasians[47]. The Chinese-specific BMI standard is more recommended for Chinese owing to its lower cut-off points for BMI categories[48] and better sensitivity and specificity for identifying risk factors of diseases[47]. Thus, in the present study, the Chinese-specific BMI criteria rather than WHO BMI international or Asian BMI categories were used.

Our study showed that excessive GWG is significantly associated with an increased risk of macrosomia, LGA and caesarean section, whereas inadequate GWG is significantly associated with an increased risk of LBW, SGA, preterm delivery and GDM. Consistent with our results, a meta-analysis published in 2017 concluded that inappropriate GWG was associated with higher risk of adverse pregnancy outcomes, including macrosomia, LGA, SGA, preterm birth and caesarean delivery[49]. Although the observation of an inverse association between GWG and the risk of GDM was consistent with several studies[15,50–52], it was contrary to our primary hypothesis. One plausible explanation was that pregnant women tend to adopt weight management once being diagnosed with GDM within 24–28 weeks[15], leading to decreased weight gain in late pregnancy.

The key point of the GWG targets study is whether the new GWG targets can improve pregnancy outcomes, compared with the IOM recommendation. The results of the comparison showed that inappropriate GWG judged by our proposed recommendations was associated with higher risk of macrosomia, LBW, LGA, SGA, preterm delivery and caesarean section, which was consistent with those judged by the IOM 2009 GWG guidelines. It seems logical that our proposed GWG recommendation is comparable with the IOM 2009 GWG guidelines and both of these two recommendations are suitable for Chinese pregnant women. Moreover, all of the AUC was above 0·50. This indicated that the GWG cut-offs proposed in the present study could well predict the occurrence of pregnancy outcomes such as macrosomia, LBW, LGA, SGA, preterm delivery, caesarean section and GDM.

To our knowledge, this is the first multicentre study restricted to Chinese population to estimate optimal GWG in Chinese pregnant women by applying predicted probability of a composite adverse pregnancy outcomes. Data were precisely and prospectively collected from a nationally representative sample across multiple cities in China, which enables us to popularise the results of the current study to some extent. Some limitations need to be addressed. First, the pre-pregnancy weight was self-reported and recall bias was inevitable. Second, the current study only focused on several adverse pregnancy outcomes but ignored some rare pregnancy outcomes such as still birth, neonatal death and congenital malformation. Third, we could not determine the appropriate GWG for obese women due to the small sample size. Further studies with a larger sample size are needed to create GWG recommendation for obese women. Fourth, all maternal and neonatal outcomes were weighted equally in the present study. However, some other specific adverse outcomes such as preterm delivery and SGA would be more serious than others like LGA.

In conclusion, inappropriate GWG was associated with several unfavourable pregnancy outcomes than an adequate GWG. The optimal GWG value (ranges) for the lowest predicted probability of combining adverse pregnancy outcomes was 15·0 kg (12·8–17·1) for underweight

pregnant women, 14·2 kg (12·1–16·4) for normal weight pregnant women and 12·6 kg (10·4–14·9) for overweight pregnant women.

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References

1. Kominiarek MA & Peaceman AM (2017) Gestational weight gain. *Am J Obstet Gynecol* **217**, 642–651.
2. Godoy AC, Nascimento SL & Surita FG (2015) A systematic review and meta-analysis of gestational weight gain recommendations and related outcomes in Brazil. *Clinics (Sao Paulo)* **70**, 758–764.
3. Johnson J, Clifton RG, Roberts JM et al. (2013) Pregnancy outcomes with weight gain above or below the 2009 Institute of Medicine guidelines. *Obstet Gynecol* **121**, 969–975.
4. Rogozinska E, Zamora J, Marlin N et al. (2019) Gestational weight gain outside the Institute of Medicine recommendations and adverse pregnancy outcomes: analysis using individual participant data from randomised trials. *BMC Pregnancy Childbirth* **19**, 322.
5. Takmaz T, Yalvac ES, Ozcan P et al. (2019) The predictive value of weight gain and waist circumference for gestational diabetes mellitus. *Turk J Obstet Gynecol* **16**, 199–204.
6. Xiao L, Ding G, Vinturache A et al. (2017) Associations of maternal pre-pregnancy body mass index and gestational weight gain with birth outcomes in Shanghai, China. *Sci Rep* **7**, 41073.
7. Li C, Liu Y & Zhang W (2015) Joint and independent associations of gestational weight gain and pre-pregnancy body mass index with outcomes of pregnancy in Chinese women: a retrospective cohort study. *PLoS One* **10**, e0136850.
8. Li N, Liu E, Guo J et al. (2013) Maternal prepregnancy body mass index and gestational weight gain on pregnancy outcomes. *PLoS One* **8**, e82310.
9. Huang A, Xiao Y, Hu H et al. (2020) Gestational weight gain charts by gestational age and body mass index for Chinese women: a population-based follow-up study. *J Epidemiol* **30**, 345–353.
10. Fang HY, Zhao LY, Ju LH et al. (2018) Prevalence of malnutrition and overweight and obesity among childbearing women aged 15–49 years in China. *Chin J Public Health* **34**, 1229–1232.
11. Chu SY, Bachman DJ, Callaghan WM et al. (2008) Association between obesity during pregnancy and increased use of health care. *N Engl J Med* **358**, 1444–1453.
12. Du MK, Ge LY, Zhou ML et al. (2017) Effects of pre-pregnancy body mass index and gestational weight gain on neonatal birth weight. *J Zhejiang Univ Sci B* **18**, 263–271.
13. Hung TH & Hsieh TT (2016) Pregestational body mass index, gestational weight gain, and risks for adverse pregnancy outcomes among Taiwanese women: a retrospective cohort study. *Taiwan J Obstet Gynecol* **55**, 575–581.
14. Aviram A, Hod M & Yogev Y (2011) Maternal obesity: implications for pregnancy outcome and long-term risks – a link to maternal nutrition. *Int J Gynaecol Obstet* **115**, Suppl. 1, S6–S10.
15. Yang W, Han F, Gao X et al. (2017) Relationship between gestational weight gain and pregnancy complications or delivery outcome. *Sci Rep* **7**, 12531.
16. Ferreira LAP, Piccinato CA, Cordioli E et al. (2020) Pregestational body mass index, weight gain during pregnancy and perinatal outcome: a retrospective descriptive study. *Einstein (Sao Paulo)* **18**, eAO4851.
17. Abenhaim HA, Kinch RA, Morin L et al. (2007) Effect of pre-pregnancy body mass index categories on obstetrical and neonatal outcomes. *Arch Gynecol Obstet* **275**, 39–43.
18. Institute of Medicine (2009) *Weight Gain during Pregnancy: Reexamining the Guidelines*. Washington (DC): National Academies Press (US).
19. Chinese Society of Obstetrics and Gynecology & Chinese Medical Association (2018) Guideline of preconception and prenatal care. *Chin J Obstet Gynecol* **53**, 7–13.
20. Yazdani S, Yosofniyapasha Y, Nasab BH et al. (2012) Effect of maternal body mass index on pregnancy outcome and newborn weight. *BMC Res Notes* **5**, 34.
21. Wong W, Tang NL, Lau TK et al. (2000) A new recommendation for maternal weight gain in Chinese women. *J Am Diet Assoc* **100**, 791–796.
22. Bracero LA & Byrne DW (1998) Optimal maternal weight gain during singleton pregnancy. *Gynecol Obstet Invest* **46**, 9–16.
23. Hirooka-Nakama J, Enomoto K, Sakamaki K et al. (2018) Optimal weight gain in obese and overweight pregnant Japanese women. *Endocr J* **65**, 557–567.

Public Health Nutrition

24. Morisaki N, Nagata C, Jwa SC *et al.* (2017) Pre-pregnancy BMI-specific optimal gestational weight gain for women in Japan. *J Epidemiol* **27**, 492–498.

25. Beyerlein A, Schiessl B, Lack N *et al.* (2009) Optimal gestational weight gain ranges for the avoidance of adverse birth weight outcomes: a novel approach. *Am J Clin Nutr* **90**, 1552–1558.

26. Cedergren MI (2007) Optimal gestational weight gain for body mass index categories. *Obstet Gynecol* **110**, 759–764.

27. Chen A, Xie C, Vuong AM *et al.* (2017) Optimal gestational weight gain: prepregnancy BMI specific influences on adverse pregnancy and infant health outcomes. *J Perinatol* **37**, 369–374.

28. Choi SK, Lee G, Kim YH *et al.* (2017) Determining optimal gestational weight gain in the Korean population: a retrospective cohort study. *Reprod Biol Endocrinol* **15**, 67.

29. Ee TX, Allen JC Jr., Malhotra R *et al.* (2014) Determining optimal gestational weight gain in a multiethnic Asian population. *J Obstet Gynaecol Res* **40**, 1002–1008.

30. Nohr EA, Vaeth M, Baker JL *et al.* (2008) Combined associations of prepregnancy body mass index and gestational weight gain with the outcome of pregnancy. *Am J Clin Nutr* **87**, 1750–1759.

31. Oken E, Kleinman KP, Belfort MB *et al.* (2009) Associations of gestational weight gain with short- and longer-term maternal and child health outcomes. *Am J Epidemiol* **170**, 173–180.

32. Sunsaneevithayakul P, Titapant V, Ruangvutilert P *et al.* (2014) Relation between gestational weight gain and pregnancy outcomes. *J Obstet Gynaecol Res* **40**, 995–1001.

33. Chen C & Lu FC (2004) The guidelines for prevention and control of overweight and obesity in Chinese adults. *Biomed Environ Sci* **17**, 1–36.

34. Huang A, Ji Z, Zhao W *et al.* (2016) Rate of gestational weight gain and preterm birth in relation to prepregnancy body mass indices and trimester: a follow-up study in China. *Reprod Health* **13**, 93.

35. Yang S, Peng A, Wei S *et al.* (2015) Pre-pregnancy body mass index, gestational weight gain, and birth weight: a cohort study in China. *PLoS One* **10**, e0130101.

36. Zhu L, Zhang R, Zhang S *et al.* (2015) Chinese neonatal birth weight curve for different gestational age. *Chin J Pediatr* **53**, 97–103.

37. Lo JO, Mission JF & Caughey AB (2013) Hypertensive disease of pregnancy and maternal mortality. *Curr Opin Obstet Gynecol* **25**, 124–132.

38. Metzger BE, Gabbe SG, Persson B *et al.* (2010) International association of diabetes and pregnancy study groups recommendations on the diagnosis and classification of hyperglycemia in pregnancy. *Diabetes care* **33**, 676–682.

39. Robillard PY, Dekker G, Boukerrou M *et al.* (2018) Relationship between pre-pregnancy maternal BMI and optimal weight gain in singleton pregnancies. *Heliyon* **4**, e00615.

40. Langford A, Joshu C, Chang JJ *et al.* (2011) Does gestational weight gain affect the risk of adverse maternal and infant outcomes in overweight women? *Matern Child Health J* **15**, 860–865.

41. DeVader SR, Neeley HL, Myles TD *et al.* (2007) Evaluation of gestational weight gain guidelines for women with normal prepregnancy body mass index. *Obstet Gynecol* **110**, 745–751.

42. Kiel DW, Dodson EA, Artal R *et al.* (2007) Gestational weight gain and pregnancy outcomes in obese women: how much is enough? *Obstet Gynecol* **110**, 752–758.

43. Hutcheon JA & Bodnar LM (2014) A systematic approach for establishing the range of recommended weight gain in pregnancy. *Am J Clin Nutr* **100**, 701–707.

44. Mestrovic Z, Roje D, Vulic M *et al.* (2017) Calculation of optimal gestation weight gain in pre-pregnancy underweight women due to body mass index change in relation to mother's height. *Arch Gynecol Obstet* **295**, 81–86.

45. LifeCycle Project-Maternal Obesity and Childhood Outcomes Study Group, Voerman E, Santos S *et al.* (2019) Association of gestational weight gain with adverse maternal and infant outcomes. *JAMA* **321**, 1702–1715.

46. Choo V (2002) WHO reassesses appropriate body-mass index for Asian populations. *Lancet* **360**, 235.

47. Zhou BF & Cooperative Meta-Analysis Group of the Working Group on Obesity in C (2002) Predictive values of body mass index and waist circumference for risk factors of certain related diseases in Chinese adults – study on optimal cut-off points of body mass index and waist circumference in Chinese adults. *Biomed Environ Sci* **15**, 83–96.

48. Wang Y, Mi J, Shan XY *et al.* (2007) Is China facing an obesity epidemic and the consequences? The trends in obesity and chronic disease in China. *Int J Obes (Lond)* **31**, 177–188.

49. Goldstein RF, Abell SK, Ranasinha S *et al.* (2017) Association of gestational weight gain with maternal and infant outcomes: a systematic review and meta-analysis. *JAMA* **317**, 2207–2225.

50. Cho EH, Hur J & Lee KJ (2015) Early gestational weight gain rate and adverse pregnancy outcomes in Korean women. *PLoS One* **10**, e0140376.

51. Hedderson MM, Gunderson EP & Ferrara A (2010) Gestational weight gain and risk of gestational diabetes mellitus. *Obstet Gynecol* **115**, 597–604.

52. MacDonald SC, Bodnar LM, Himes KP *et al.* (2017) Patterns of gestational weight gain in early pregnancy and risk of gestational diabetes mellitus. *Epidemiology* **28**, 419–427.