ARTICLE

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Estimated optimal gestational weight gain for pregnant women with gestational diabetes mellitus: a prospective cohort study in China

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OBJECTIVES: We aimed to evaluate the inter-hospital variability of gestational weight gain (GWG) among women with gestational diabetes mellitus (GDM) in China and explore GDM-specific optimal GWG relative to the National Academy of Medicine (NAM) targets.

METHODS: A prospective multicenter University Hospital Advanced Age Pregnant Cohort study was conducted from March 2017 to June 2021 at eight hospitals in China. The range of mean GWG across hospitals and the intraclass correlation coefficient (ICC) were used to evaluate the inter-hospital variability of GWG. For normal-weight and overweight women with GDM, potential optimal GWGs were derived by minimizing the joint risk of small and large for gestational age (SGA and LGA), and the incidences of adverse perinatal outcomes were compared between women who met the optimal GWGs and those who met the NAM targets.

RESULTS: A total of 3,013 women with GDM and 9,115 women without GDM were included. The GWG variation among hospitals was larger in women with GDM (range: 10.0–14.1 kg, ICC = 7.1%) than in women without GDM (range: 13.0–14.5 kg, ICC = 0.7%). The estimated optimal GWGs for women with GDM were lower than the NAM targets, as 9.5–14.0 kg for normal-weight and 3.0–7.5 kg for overweight women. Women with GDM who met the optimal GWGs had lower incidences of LGA and macrosomia compared to those who met the NAM targets, with no significant increase in the incidences of SGA, preterm birth, etc.

CONCLUSIONS: The marked variation of GWG among hospitals in women with GDM indicates the need to develop optimal GWGs for them. The potential optimal GWGs for women with GDM might be lower than the NAM targets, likely benefiting the perinatal outcomes.

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INTRODUCTION

Gestational diabetes mellitus (GDM), a common condition involving glucose intolerance that onsets or is first recognized during pregnancy [1], increases the risks of adverse perinatal outcomes such as macrosomia and neonatal hypoglycemia [2, 3], and the future risk of type 2 diabetes for the mother and offspring [4, 5]. GDM is prevalent in many countries [6]. The worldwide incidence was 13.2% in 2019, affecting approximately 17.1 million births [7], and the corresponding values in China were 14.8% and 2.2 million births [8]. The incidence is particularly high in women of advanced maternal age (AMA), reaching 27% [8].

Gestational weight gain (GWG), usually defined as a change in maternal weight measured before pregnancy and prior to delivery, is associated with the short- and long-term health of the mother and offspring [9]. GWG in women with GDM is particularly concerning because GWG affects the occurrence and prognosis of GDM [10] and has a synergistic effect with GDM on perinatal outcomes [11]. To improve glycemic control, physical activities and dietary modifications are generally advocated for women with GDM [12], likely leading to a lower GWG than women without GDM [13]. Nevertheless, due to the lack of GWG recommendations for women with GDM, their GWG might vary among hospitals [14]. Thus far, no studies have evaluated the inter-hospital variability of GWG in women with GDM.

Whether the National Academy of Medicine (NAM) targets are applicable to women with GDM remains unclear [15]. Some previous studies reported that a GWG below the NAM targets in women with GDM improved glycemic control [16], decreased the risks of large for gestational age (LGA) and macrosomia [14], without increasing the risk of small for gestational age (SGA) or preterm birth [14, 17–19], indicating that the potential optimal GWGs for women with GDM might be lower than the NAM targets. However, to what extent the NAM targets should be left-shifted has not been determined. Two studies assessed the effects of GWG, subtracting 1–2 kg from the NAM targets, on perinatal outcomes in women with GDM but reported inconsistent results [20, 21].

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In addition, neither of them considered the effects of pre-pregnancy body mass index (BMI).

In this prospective multicenter cohort study, we aimed to evaluate the inter-hospital variability of GWG among women with GDM in China, and to explore the GDM-specific optimal GWG relative to the NAM targets according to maternal pre-pregnancy BMI.

METHODS

Cohort and study participants

The data were drawn from the prospective multicenter University Hospital Advanced Age Pregnant (UNIHOPE) Cohort study conducted in China from March 2017 to June 2021 [22]. The cohort comprised a singleton and a twin pregnancy subcohorts. This study was based on the singleton pregnancy subcohort, which encompassed nine tertiary hospitals in the cities of Beijing, Shanghai, Guangzhou, Shenyang, Wuhan, Chongqing, and Chengdu, covering the eastern, central, and western regions of China. For this subcohort, the inclusion criteria were women of AMA planning to receive prenatal healthcare and delivery service at the study hospitals. Additionally, some younger women (≤35 years; proportion of 25%) were recruited for potential comparisons between the two populations. The exclusion criteria were women with no ability to provide informed consent or with mental disorders. The participants were enrolled and completed early pregnancy follow-up before 14 gestational weeks, completed mid-pregnancy follow-up at 24 to 28 gestational weeks, and provided delivery information after delivery and before discharge.

During the cohort period, 15,597 pregnant women at the nine hospitals who delivered a live birth were initially considered in this study. The exclusion criteria were (1) pregnant women at the hospital with enrollment size <200 ($n = 105$); (2) missing maternal baseline characteristics or maternal age <20 or >50 years ($n = 563$); (3) missing delivery information, gestational age at delivery <24 or >44 weeks, or birth weight <1000 or >5000 g ($n = 443$); (4) missing ($n = 1,396$) or suspicious ($n = 296$; defined as the value exceeding the range of median ± 3 interquartile ranges [IQRs]) maternal height, weight, or GWG; and (5) diagnosis of pre-gestational diabetes ($n = 662$) or missing diabetes diagnosis ($n = 4$). Finally, 12,128 pregnant women at eight hospitals were included in the analysis, consisting of 3,013 women with GDM and 9,115 women without GDM. In analysis of GWG after OGTT, women who delivered before 28 gestational weeks ($n = 12$), or with missing ($n = 1978$) or suspicious ($n = 300$) weight or GWG in the early or mid-pregnancy were further excluded, leaving 2,611 women with GDM and 7227 women without GDM included. The maternal characteristics between the excluded and the included women were similar except for maternal age, ethnicity, parity, and pre-pregnancy BMI, as detailed in our previous study [23].

Data collection and definitions

Information about maternal demographics, reproductive history, prenatal care of the current pregnancy, and perinatal outcomes was collected using a structured questionnaire by nurses or obstetricians. According to the criteria of the International Association of Diabetes and Pregnancy Study Groups (IADPSG) [24], GDM was diagnosed when a 75 g oral glucose tolerance test (OGTT) at 24 to 28 gestational weeks met one of the following three criteria: (1) fasting plasma glucose ≥ 5.1 mmol/L, (2) 1 h plasma glucose ≥10.0 mmol/L, or (3) 2 h plasma glucose ≥ 8.5 mmol/L.

The pre-pregnancy weight was self-reported at enrollment; the pre-delivery weight and height were measured at the hospital. The median difference between the date of the pre-delivery weight measurement and the delivery date was one day. The pre-pregnancy BMI (kg/m^2) was calculated as the pre-pregnancy weight divided by the height squared and categorized as underweight (<18.5 kg/m^2), normal-weight (18.5 to <24.0 kg/m^2), overweight (24.0 to <28.0 kg/m^2), or obese (≥28.0 kg/m^2) according to the Chinese criteria [25], which were recommended when applying the NAM targets to Chinese women [26]. The total GWG (kg) was calculated as the pre-delivery weight minus the pre-pregnancy weight and categorized as insufficient, adequate, or excessive according to the NAM targets [15]. As OGTT was performed at the end of mid-pregnancy, GWG after OGTT was approximate to the GWG during late pregnancy calculated as pre-delivery weight minus weight at the 27th gestational week. The weekly GWG after OGTT was calculated as the GWG after OGTT divided by 12 gestational weeks (the median gestational age at delivery [39 weeks] minus 27 weeks). If the mid-pregnancy follow-up did not occur at the 27th gestational week, a linear interpolation method was used to estimate the weight [27].

Adverse perinatal outcomes included SGA, LGA, macrosomia, preterm birth, neonatal intensive care unit (NICU) admission, cesarean delivery, postpartum hemorrhage (PPH), and gestational hypertensive disorders (GHDs). SGA was defined as birth weight <10th percentile for gestational age and LGA as birth weight > 90th percentile for gestational age, according to the Chinese sex- and gestational week-specific birth weight standards [28, 29]. Macrosomia was defined as birth weight ≥4000 g, preterm birth as birth with gestational age at delivery <37 weeks, PPH as blood loss >500 mL for vaginal delivery or >1000 mL for cesarean delivery, and GHDs as new-onset systolic blood pressure >140 mmHg or diastolic blood pressure >90 mmHg after 20 gestational weeks.

Statistical analyses

The continuous variables were expressed as means ± standard deviations (SDs) or medians (IQRs), depending on the normality of the data distribution. The categorical variables were expressed as frequencies (%).

The range of mean GWG across the eight hospitals and the intraclass correlation coefficient (ICC) derived from a random intercept model were used to evaluate the inter-hospital variability of GWG [30]. The least squares mean [31] and conditional ICC [32] were further calculated to account for the differences in maternal characteristics among hospitals.

The potential optimal GWGs for women with GDM were developed by the method of minimizing the joint risk of SGA and LGA, which has been used previously in generating GWG targets for general pregnant women [33, 34]. The potential optimal GWGs were developed for normal-weight ($n = 1,919$) and overweight women ($n = 747$), but not for underweight ($n = 163$) or obese women ($n = 184$) because of their limited sample sizes. The adjusted predictive probabilities of SGA and LGA with respect to GWG were estimated by mixed-effects logistic regression with the marginal standardization method [35]. The potential optimal GWG point was the GWG with the lowest sum of the predictive probability of SGA and LGA. The difference between the potential optimal GWG point and the midpoint of the NAM range was calculated, and then the potential optimal GWGs were obtained by subtracting the difference from both the NAM upper and lower limits. Alternatively, the potential optimal GWGs were estimated as the GWG range with the sum of predictive probabilities increasing no more than 0.5% from the potential optimal GWG point [34]. The maximum increase of 0.5% was selected to avoid excessively wide potential optimal GWGs [33]. The adjusted covariates included maternal age, ethnicity, parity, conception mode, and gestational age. Center effects were adjusted by including random effects of centers. To obtain the potential optimal GWGs for the subgroup of AMA and younger women, the mixed-effects logistic regression with the prediction at the modes method was used [35], fixing the maternal age at ≥35 years and <35 years, respectively. For facilitating clinical use, the potential optimal GWG and weekly GWG after OGTT were also estimated.

Mixed-effects logistic regression was performed to estimate the adjusted absolute risk reduction (ARR) [36], to compare the incidences of the adverse perinatal outcomes between women who met the potential optimal GWGs and those who met the NAM targets. The incidences of the adverse outcomes were additionally compared between women who met the potential optimal GWGs only and those who met the NAM targets only, with those who met both excluded.

Statistical analyses were performed using R software (version 4.0; R Development Core Team, Vienna, Austria). Statistical tests were two-sided, with the significance level set at 0.05.

RESULTS

Characteristics of study participants

The characteristics of the women with and without GDM are shown in Table 1. Women with versus without GDM were more likely to be of AMA (89.6% *vs.* 78.4%), to undergo in vitro fertilization (IVF) or intracytoplasmic sperm injection (ICSI) (18.0% *vs.* 12.5%), to have a higher pre-pregnancy BMI (22.8 ± 3.0 *vs.* 21.8 ± 2.8 kg/m^2), to give birth by cesarean delivery (68.6% *vs.* 63.7%), and to deliver preterm births (12.2% *vs.* 9.0%) with a higher incidence of NICU admission (7.1% *vs.* 5.4%). Although women with versus without GDM were more likely to deliver lower weight births (3231.0 ± 511.0 *vs.* 3262.0 ± 482.0 g), the incidences of LGA, SGA, and macrosomia were similar between the two groups. For women with GDM, 15.3% were treated with

Table 1. Characteristics of study participants.

Characteristic	Women without GDM ($n = 9115$)	Women with GDM ($n = 3013$)	P^a
Maternal age, year	36.0 (35.0 to 38.0)	37.0 (36.0 to 39.0)	<0.001
<35	1966 (21.6)	312 (10.4)	<0.001
≥35 and <40	5829 (63.9)	2047 (67.9)	
≥40	1320 (14.5)	654 (21.7)	
Han ethnicity	8780 (96.3)	2911 (96.6)	0.459
Multipara	5296 (58.1)	1754 (58.2)	0.914
Conception mode			
Natural conception	7861 (86.2)	2423 (80.4)	<0.001
IVF or ICSI	1139 (12.5)	542 (18.0)	
Others	115 (1.3)	48 (1.6)	
Pre-pregnancy BMI, kg/m^2	21.8 ± 2.8	22.8 ± 3.0	<0.001
Underweight	832 (9.1)	163 (5.4)	<0.001
Normal-weight	6484 (71.1)	1919 (63.7)	
Overweight	1530 (16.8)	747 (24.8)	
Obese	269 (3.0)	184 (6.1)	
Cesarean delivery	5803 (63.7)	2066 (68.6)	<0.001
Birth weight, g			
3262.0 ± 482.0			
3231.0 ± 511.0	0.008		
SGA	677 (7.4)	254 (8.4)	0.073
LGA	724 (7.9)	257 (8.5)	0.306
Macrosomia	407 (4.5)	141 (4.7)	0.623
Gestational age, week	39.0 (38.3 to 39.9)	38.6 (38.0 to 39.6)	<0.001
Preterm birth (<37)	822 (9.0)	369 (12.2)	<0.001
NICU admission	489 (5.4)	214 (7.1)	<0.001

Data are expressed as means ± SDs, medians (IQRs), or frequencies (%).
[a]Statistical significance for continuous values using Student's *t*-test or Wilcoxon rank-sum test, for categorical values using Chi-squared test.
GDM gestational diabetes mellitus, *IVF* in vitro fertilization, *ICSI* intracytoplasmic sperm injection, *BMI* body mass index, *SGA* small for gestational age, *LGA* large for gestational age, *NICU* newborn intensive care unit.

insulin, and the rest were treated with nutritional diet and/or physical exercise.

Inter-hospital variability of GWG

The GWG was 11.4 ± 5.1 kg and 13.5 ± 5.0 kg in women with and without GDM, respectively. The mean GWG across the eight hospitals ranged from 10.0 to 14.1 kg in women with GDM, and from 13.0 to 14.5 kg in women without GDM, with corresponding ICCs of 7.1% and 0.7%, respectively. After adjustment for maternal characteristics, the least squares mean of GWG across the eight hospitals ranged from 10.7 to 14.8 kg in women with GDM, and from 13.1 to 14.8 kg in women without GDM, with corresponding conditional ICCs of 7.0% and 0.6%, respectively (Supplemental Table 1).

Potential optimal GWGs for women with GDM

The predictive probability curves of SGA, LGA, and sum of SGA and LGA (SGA + LGA) with respect to GWG for normal-weight and overweight women with GDM are shown in Fig. 1. The predictive probability of SGA + LGA was lowest at 11.7 kg of GWG in normal-weight and 5.2 kg in overweight women. Correspondingly, the potential optimal GWGs were 9.5–14.0 kg for normal-weight and 3.0–7.5 kg for overweight women. The results were similar when the optimal GWGs were estimated as the GWG range with the sum of predictive probabilities increasing no more than 0.5% from the optimal GWG point, as 9.1–14.3 kg for normal-weight and 2.7–7.6 kg for overweight women (Table 2). The potential optimal GWGs were slightly lower in women of AMA than in younger women (Supplemental Table 2 and Supplemental Fig. 1).

Compared to women with GDM who met the NAM targets, those who met the potential optimal GWGs had lower incidences of LGA (adjusted ARR = − 2.8%, 95% CI: − 5.2% to −0.3%) and macrosomia (adjusted ARR = − 3.0%, 95% CI: − 4.8% to −1.1%), with no significant differences in the incidences of SGA, preterm birth, NICU admission, cesarean delivery, PPH, or GHDs. In subgroup analyses, the decreased incidence of macrosomia was consistently significant in normal-weight (adjusted ARR = −2.5%, 95% CI: −4.5% to −0.5%) and overweight women (adjusted ARR = −4.4%, 95% CI: −8.0% to −0.7%), as was the decreased incidence of LGA in overweight women (adjusted ARR = −5.3%, 95% CI: −9.9% to −0.6%). The results remained when the comparisons were performed between women who met the potential optimal GWGs only and those who met the NAM targets only, with those who met both excluded (Table 3).

Potential optimal GWG after OGTT for women with GDM

The potential optimal GWG and weekly GWG after OGTT according to GWG before OGTT are shown in Supplemental Table 3. The potential optimal GWG after OGTT decreased with the increasing of GWG before OGTT. When the GWG before OGTT was ≥10.0 kg for normal-weight or ≥5.0 kg for overweight women, the potential optimal GWG after OGTT was negative.

DISCUSSION

In this prospective multicenter cohort study in China, the GWG of women with GDM varied more markedly among hospitals than that of women without GDM. The potential optimal GWGs for women with GDM were lower than the NAM targets, as 9.5–14.0 kg for normal-weight and 3.0–7.5 kg for overweight women. Women with GDM who met the potential optimal GWGs had lower incidences of LGA and macrosomia, without significant increase in the incidences of SGA, preterm birth, NICU admission, cesarean delivery, PPH, or GHDs, as compared to those who met the NAM targets.

This is, to our knowledge, the first report of a higher inter-hospital variability of GWG in women with than without GDM. For example, the hospital factors accounted for 7.1% of the GWG variation in women with GDM, compared to 0.7% in women without GDM (ICC: 7.1% *vs*. 0.7%) [30]. The results remained after adjustment for maternal characteristics, indicating that the marked variation of GWG in women with GDM is likely due to the varied weight-gain management strategies among hospitals, necessitating the development of GDM-specific optimal GWGs.

Few studies have attempted to determine optimal GWGs for women with GDM [20, 21, 37]. The study by Wu et al. among 1,820 Chinese women with GDM tried to develop optimal GWG rates during the second and third trimesters, but the rates in all pre-pregnancy BMI categories were higher than the NAM recommendations [37], which would possibly jeopardize the glycemic control and birth weight outcomes [16]. Another two studies examined the effects of a lower GWG, subtracting 1–2 kg from the NAM targets, on perinatal outcomes, but reported inconsistent results [20, 21]. The study by Wong et al. among 2638 Australian women with GDM found that the lower GWG did not improve perinatal outcomes [21], while the study by Xu et al. among 1200 Chinese women with GDM found that the lower GWG was associated with decreased risks of

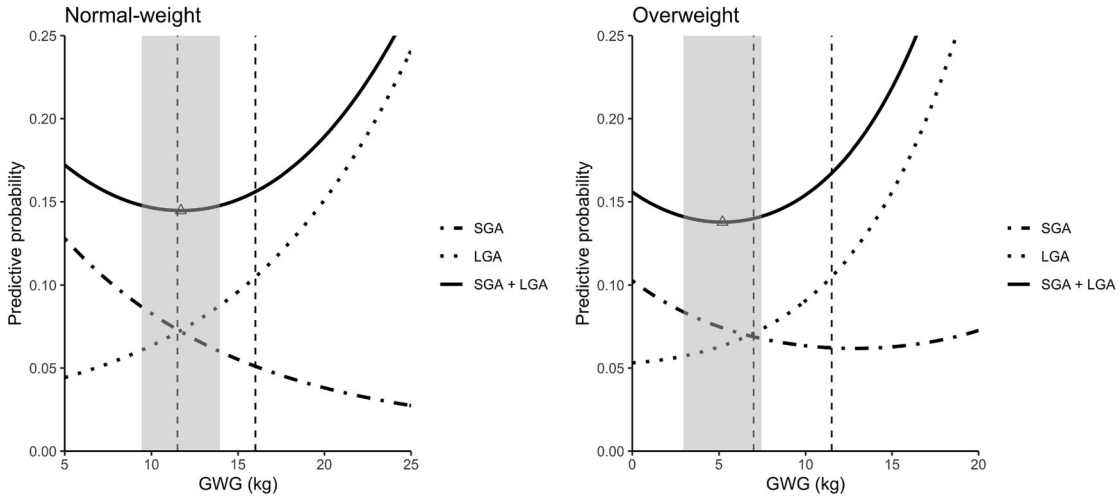

Fig. 1 Predictive probability curves of SGA, LGA, and sum of SGA and LGA with respect to GWG. Predictive probability was estimated by mixed-effects logistic regression with the marginal standardization method. The area within the two vertical dashed lines corresponds to the NAM targets, the shading to the potential optimal GWGs (the primary method), and the triangle to the lowest predictive probability of SGA + LGA.

Table 2. Potential optimal GWGs for women with GDM *vs.* NAM targets.

Group	Normal-weight	Overweight
NAM targets, kg	11.5–16.0	7.0–11.5
Potential optimal GWGs, kg		
Primary method[a]	9.5–14.0	3.0–7.5
Alternative method[b]	9.1–14.3	2.7–7.6

[a]The potential optimal GWGs were obtained by subtracting the difference, between the potential optimal GWG point and the midpoint of the NAM range, from both the NAM upper and lower limits.
[b]The potential optimal GWGs were estimated as the GWG range with the sum of predictive probabilities increasing no more than 0.5% from the potential optimal GWG point.
GWG gestational weight gain, *GDM* gestational diabetes mellitus, *NAM* National Academy of Medicine.

LGA and macrosomia, with a slightly increased risk of SGA [20]. The lower GWG in these two studies was somewhat subjective, and neither study took account of the pre-pregnancy BMI, a potential modifier for the association of GWG with perinatal outcomes [38]. We estimated the potential optimal GWGs by minimizing the joint risk of SGA and LGA for normal-weight and overweight women with GDM, and found that subtracting 2.0 kg from the NAM targets for normal-weight and 4.0 kg for overweight women might be more reasonable. We also found that if the GWG before OGTT was excessive, weight loss after OGTT might be recommended, similar to previous studies [10, 39].

In our study, the potential optimal GWGs compared to the NAM targets in women with GDM decreased the risks of LGA and macrosomia, in line with previous studies [40, 41]. A lower GWG contributes to controlling maternal hyperglycemia and excessive fetal growth [10]. We also found that the potential optimal GWGs did not increase the risk of SGA or preterm birth, consistent with a meta-analysis which found that a GWG below the NAM targets among women with GDM did not increase the risk of SGA or preterm birth [14]. This might relate to that a lower GWG in women with GDM could reduce the risk of GHDs [42], a risk factor for SGA and preterm birth [43]. In our study, the incidence of GHDs tended to decrease by 2.5 percentage points in women who met the potential optimal GWGs compared to those who met the NAM targets (adjusted ARR = −2.5%, $P = 0.08$). In addition, perhaps women with a lower GWG were more likely to accept nutritional diet interventions, have better diet quality, and obtain more attention from doctors, preventing SGA and preterm birth [18, 44, 45].

This study had strengths. Using data from a prospective multicenter cohort in China, we firstly reported a higher inter-hospital variability of GWG in women with than without GDM, possibly reflecting the varied weight-gain management strategies in clinical practice due to the lack of GWG recommendations for women with GDM. Based on the modeling strategies that have been used previously [33, 34], we developed potential optimal GWGs for normal-weight and overweight women with GDM, which is crucial to prenatal care providers and clinicians, particularly given the increasing prevalence of GDM [46].

This study also had limitations. First, nearly 90% of women with GDM in our study were of AMA, thus caution is needed when generalizing the potential optimal GWGs to younger women, although our data showed comparable optimal GWGs between the two populations. Additionally, the potential optimal GWGs were estimated from Chinese women, and might not be applicable to other ethnic women, as Chinese women with GDM were less likely to have adverse perinatal outcomes, different from Caucasian women [47]. Second, despite the larger sample size than the previous studies [20, 21, 37], the potential optimal GWGs were only explored for normal-weight and overweight women but not for underweight or obese women, considering that the small number of participants would lead to unstable results. Third, potential bias might be introduced as 17% of participants were excluded due to missing or suspicious data, despite the similar characteristics between the included and excluded women. Fourth, potential bias might also be introduced by the self-reported pre-pregnancy weight, despite a strong positive correlation between self-reported and measured pre-pregnancy weight [48].

In conclusion, the marked variation of GWG in women with GDM likely reflects varied weight-gain management strategies among hospitals in China, necessitating the development of optimal GWGs. The potential optimal GWGs, lower than the NAM targets, likely benefit the perinatal outcomes. Nevertheless, it should be noted that the potential optimal GWGs in our study were developed for ordinary women with GDM; special groups such as those with other pregnancy complications should

Table 3. Incidences of adverse perinatal outcomes of women with GDM who met the NAM targets *vs*. those who met the potential optimal GWGs.

Outcome	Cases (%) of adverse outcomes				Adjusted ARR (95% CI)[a]	Adjusted ARR (95% CI)[b]
	NAM targets[a]	Optimal GWGs[a]	NAM targets only[b]	Optimal GWGs only[b]		
Normal-weight or overweight[c]	$n = 1016$	$n = 917$	$n = 589$	$n = 557$		
SGA	62 (6.1)	74 (8.1)	33 (5.6)	49 (8.8)	1.6 (−0.7 to 3.9)	3.0 (−0.3 to 6.3)
LGA	89 (8.8)	52 (5.7)	58 (9.8)	22 (3.9)	−2.8 (−5.2 to −0.3)*	−5.7 (−8.9 to −2.5)***
Macrosomia	54 (5.3)	20 (2.2)	39 (6.6)	6 (1.1)	−3.0 (−4.8 to −1.1)**	−5.2 (−7.5 to −2.9)***
Preterm birth	104 (10.2)	109 (11.9)	59 (10.0)	75 (13.5)	2.6 (−0.8 to 5.9)	4.8 (−0.1 to 9.8)
NICU admission	73 (7.2)	64 (7.0)	44 (7.5)	41 (7.4)	−0.9 (−3.4 to 1.5)	−1.6 (−5.0 to 1.9)
Cesarean delivery	709 (69.8)	600 (65.4)	415 (70.5)	347 (62.3)	−3.7 (−17.8 to 10.3)	−6.9 (−25.8 to 12.0)
PPH	49 (4.8)	37 (4.0)	31 (5.3)	22 (3.9)	−1.0 (−2.9 to 0.9)	−1.7 (−4.3 to 0.9)
GHDs	92 (9.1)	63 (6.9)	61 (10.4)	39 (7.0)	−2.5 (−5.2 to 0.3)	−4.1 (−7.9 to −0.4)*
Normal-weight[d]	$n = 708$	$n = 753$	$n = 321$	$n = 398$		
SGA	43 (6.1)	62 (8.2)	16 (5.0)	38 (9.5)	1.7 (−0.8 to 4.3)	4.1 (−0.1 to 8.3)
LGA	61 (8.6)	46 (6.1)	30 (9.3)	16 (4.0)	−2.1 (−4.8 to 0.6)	−5.1 (−9.2 to −1.1)*
Macrosomia	34 (4.8)	17 (2.3)	19 (5.9)	3 (0.8)	−2.5 (−4.5 to −0.5)*	−5.0 (−7.8 to −2.1)***
Preterm birth	69 (9.7)	83 (11.0)	32 (10.0)	50 (12.6)	1.8 (−1.7 to 5.3)	4.4 (−1.4 to 10.1)
NICU admission	43 (6.1)	43 (5.7)	19 (5.9)	22 (5.5)	−0.7 (−3.1 to 1.6)	−1.5 (−5.3 to 2.2)
Cesarean delivery	485 (68.5)	488 (64.8)	218 (67.9)	240 (60.3)	−3.1 (−18.7 to 12.5)	−7.2 (−30.0 to 15.5)
PPH	37 (5.2)	31 (4.1)	20 (6.2)	16 (4.0)	−1.3 (−3.7 to 1.0)	−2.2 (−5.7 to 1.2)
GHDs	46 (6.5)	40 (5.3)	22 (6.9)	17 (4.3)	−1.2 (−3.8 to 1.5)	−2.8 (−6.6 to 0.9)
Overweight[d]	$n = 308$	$n = 164$	$n = 268$	$n = 159$		
SGA	19 (6.2)	12 (7.3)	17 (6.3)	11 (6.9)	1.3 (−4.0 to 6.7)	0.8 (−4.6 to 6.2)
LGA	28 (9.1)	6 (3.7)	28 (10.4)	6 (3.8)	−5.3 (−9.9 to −0.6)*	−6.5 (−11.6 to −1.3)*
Macrosomia	20 (6.5)	3 (1.8)	20 (7.5)	3 (1.9)	−4.4 (−8.0 to −0.7)*	−5.3 (−9.6 to −1.0)*
Preterm birth	35 (11.4)	26 (15.9)	27 (10.1)	25 (15.7)	5.4 (−3.3 to 14.0)	7.0 (−2.1 to 16.1)
NICU admission	30 (9.7)	21 (12.8)	25 (9.3)	19 (11.9)	−0.4 (−8.4 to 7.6)	−0.9 (−8.7 to 7.0)
Cesarean delivery	224 (72.7)	112 (68.3)	197 (73.5)	107 (67.3)	−6.1 (−36.9 to 24.7)	−7.3 (−39.8 to 25.1)
PPH	12 (3.9)	6 (3.7)	11 (4.1)	6 (3.8)	0.2 (−3.4 to 3.7)	−0.04 (−3.9 to 3.9)
GHDs	46 (14.9)	23 (14.0)	39 (14.6)	22 (13.8)	−3.1 (−11.1 to 5.0)	−3.0 (−11.2 to 5.3)

[a]Women who met the potential optimal GWGs (9.5–14.0 kg for normal-weight and 3.0–7.5 kg for overweight women) and those who met the NAM targets (11.5–16.0 kg for normal-weight and 7.0–11.5 kg for overweight women).

[b]Women who met the potential optimal GWGs only (9.5–11.5 kg for normal-weight and 3.0–7.0 kg for overweight women) and those who met the NAM targets only (14.0–16.0 kg for normal-weight and 7.5–11.5 for overweight women), with those who met both excluded.

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Mixed-effects logistic regression was used to estimate the adjusted ARR, with adjustment for the covariates of maternal age, pre-pregnancy BMI (in normal-weight or overweight group [c], but not in normal-weight group [d] or in overweight group [d]), ethnicity, parity, and conception mode for SGA, LGA, and preterm birth, further adjustment of gestational age for macrosomia, NICU admission, cesarean delivery, PPH, and GHDs.

ARR absolute risk reduction, *CI* confidence interval, *GDM* gestational diabetes mellitus, *GWG* gestational weight gain, *NAM* National Academy of Medicine, *SGA* small for gestational age, *LGA* large for gestational age, *NICU* newborn intensive care unit, *PPH* postpartum hemorrhage, *GHDs* gestational hypertension disorders.

cautiously use these targets. The potential optimal GWGs should also be examined in larger and more representative samples, including younger, underweight, and obese women.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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AUTHOR CONTRIBUTIONS

JL, YZ and HL conceived the study; ZC and YZ wrote the manuscript; ZC performed the statistical analysis; YW, HL and JL contributed to the critical review of the manuscript; YW, YZ, HL, ZC, HY and JL participated in the data acquisition; and JL had full access to all the data in the study, and takes responsibility for the integrity and analysis. All authors read and approved the final manuscript.

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COMPETING INTERESTS

The authors declare no competing interests.

ETHICAL APPROVAL

The study was approved by the Institutional Review Board of Peking University Third Hospital (approval number: IRB00006761-2016145), and all participants provided informed consent.

ADDITIONAL INFORMATION

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