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Gestational weight gain trajectories over pregnancy and their association with maternal diet quality: Results from the PRINCESA cohort

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ABSTRACT

Objective: The aims of this study were to characterize, among pregnant Mexican women, gestational weight gain (GWG) trajectories; assess associations of maternal dietary quality score (MDQS) with GWG during early-mid pregnancy, middle pregnancy, late pregnancy, and prolonged pregnancy; and evaluate the association between MDQS and adequacy of GWG, throughout pregnancy. We hypothesized that higher MDQS adherence is protective against insufficient or excessive GWG across pregnancy and that the association between MDQS adherence and GWG would vary by prepregnancy body mass index (BMI) category.
Methods: We analyzed data from 660 pregnant women participating in the PRINCESA (Pregnancy Research on Inflammation, Nutrition and City Environments: Systematic Analyses) cohort in Mexico City, 2009 to 2014. Repeated measures of dietary intake and mother's weight were obtained during pregnancy. Individual GWG trajectories were modeled in a multilevel regression framework. Associations between MDQS (low, medium, and high adherence) and GWG were investigated using mixed-effect regression models with linear splines.
Results: Women with prepregnancy BMI of ≥30 kg/m^2 had a slower rate of GWG (RGWG) compared with other categories. A higher adherence to MDQS was protective against an insufficient (odds ratio [OR], 0.63; 95% confidence interval [CI], 0.42–0.95; *P* = 0.03) and an excessive RGWG (OR, 0.62; 95% CI, 0.41–0.94; *P* = 0.03) throughout pregnancy, adjusting for prepregnancy BMI, energy intake, maternal age, educational level, parity, fetal sex, marital status, and physical activity. Associations between diet and RGWG differed by gestational period.
Conclusion: A better quality diet, as measured by MDQS, was associated with appropriate GWG during pregnancy in the PRINCESA cohort.

Introduction

Epidemiologic studies link women's nutritional status and diet during pregnancy to later risk for non-communicable diseases among offspring [1]; these factors also influence the growth, metabolism, and development of the fetus [2,3]. Gestational weight gain (GWG) is a complex phenotype that is influenced by maternal responses to pregnancy, such as gestational fat deposition and blood volume expansion, fetal growth, placental size, and amniotic fluid volume [4,5].

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Independently of prepregnancy body mass index (BMI), GWG has been shown to influence both maternal and infant outcomes [6]. Insufficient gestational weight gain (IGWG) increases the risk for preterm birth and low birth weight (LBW). In contrast, excessive gestational weight gain (EGWG) is associated with an increased risk for pregnancy-induced hypertension, preeclampsia, emergency cesarean delivery, and macrosomia [5,7]. In addition, women who gain excessive weight are at higher risk for postpartum weight retention, which may influence their susceptibility to developing overweight and obesity in the longer term and increase perinatal risks in subsequent pregnancies [6,7].

Multiple variables have been reported as predictors of EGWG, including nulliparity, pregestational overweight, low income, black or Hispanic ethnicity, unmarried status, limited education, and young maternal age [5,8]. Nevertheless, little is known about the association between modifiable risk lifestyle factors, such as diet, and GWG. Designing studies on how maternal diet can influence GWG is challenging because of the physiologic adaptations that occur in pregnancy, the multiple interactions between nutrients and food groups, and the importance of the prepregnancy nutritional status of the mother, which is often difficult to characterize in cohorts that enroll women who are already pregnant. Current literature provides evidence that energy and protein intake is associated with GWG [9–12], but the roles of individual nutrients have not been fully elucidated [9–11,13]. With respect to food groups, those that have been reported as associated with EGWG are sweets, processed food [11,13,14], sweetened beverages [15,16], snacks, fish, and bread [16]. Evaluation of diet quality to assess overall adequacy of dietary intake [17] has advantages over evaluation of nutrients or food groups separately, in part because intakes of different nutrients are often highly correlated [18]. However, despite these advantages, epidemiologic studies that link a priori dietary pattern adherence to GWG are scarce and inconsistent and most of them used a cross-sectional design [14,18,19].

Hillesund et al. [19] found a positive association between the New Nordic Diet score (fruits and vegetables, whole grains, potatoes, and fish) and EGWG (odds ratio [OR], 0.93; 95% confidence interval [CI], 0.87–0.99; $P = 0.02$). Shin et al. [14] reported that the Healthy Eating Index-2005 (HEI-2005) was not determinant of adequate GWG, although inadequate intake of total vegetables (OR, 3.8; 95% CI, 1.1–13.2, $P = 0.03$) and oils (OR 2.8; 95% CI 1.2–6.4, $P = 0.02$) were associated with EGWG. Similarly, Rifas-Shiman et al. [20] found that Alternate Healthy Eating Index, slightly modified for pregnancy (AHEI-P), assessed in the first trimester of pregnancy was not associated with EGWG (OR, 0.99; 95% CI, 0.94–1.04). Only one study [18] has evaluated GWG as a longitudinal outcome (but maternal diet was assessed only once) and concluded that an a priori-defined pattern based on national dietary recommendations of the Netherlands was not associated with GWG.

To our knowledge, no study has simultaneously evaluated the maternal diet and GWG longitudinally during pregnancy. Evaluating repeated weight measurements during pregnancy in a cohort with detailed dietary intake data provides an opportunity to evaluate this association and avoid the limitations of cross-sectional studies or single measures of dietary intake.

HEI-2005 and AHEI-P have been used to evaluate the association between diet quality and a variety of pregnancy outcomes [20,21]; however, these a priori indices have been generated from studies done mostly in populations with little representation of Mexicans. In contrast, the new Maternal Dietary Quality Score (MDQS) was calculated using food components principally based on Mexican Dietary Guidelines (MDG) [22], so this score serves as indicator of a healthy, traditional, and sustainable national diet.

The aims of the present study were to conduct a longitudinal, repeated measures analysis to achieve the following:

1. Characterize GWG trajectories among Mexican women.
2. Assess the effect of MDQS on GWG during early-mid pregnancy (0–20 wk), middle pregnancy (≥20 and <30 wk), late pregnancy (30–40 wk), and prolonged pregnancy (≥40 wk of gestation).
3. Evaluate the association between MDQS and adequacy of GWG throughout pregnancy.

Materials and methods

Study design

We analyzed data from a prospective cohort, now known as the PRINCESA (Pregnancy Research on Inflammation, Nutrition, & City Environment: Systematic Analyses) cohort, of pregnant women conducted in Mexico City [23]. The main purpose of the cohort was to investigate the mechanisms by which exposure to air pollutants during pregnancy could lead to perinatal complications such as preterm birth and intrauterine growth restriction (IUGR).

From February 2009 to November 2014, we recruited 935 pregnant women who resided in diverse regions of metropolitan Mexico City. The women were recruited at the Instituto Nacional de Perinatología, public health clinics throughout the city, and the Hospital Materno Infantil Inguarán, a perinatal hospital within the Mexico City government's public hospital network. Human-subject approval for the study was obtained from the University of Michigan Institutional Review Board and the Ethics in Human Subjects and Research Committees of the participating Mexican institutions.

Inclusion criteria were reliable recall of last menstruation; agreement to prenatal visits every 4 wk throughout their current pregnancy; and written consent for their inclusion in the study. Exclusion criteria were previous presence of any medical or obstetric complication in the current pregnancy and presence of multiple fetuses. Eligibility was determined at screening and confirmed at the first visit. Women who developed pregnancy complications such as gestational diabetes and preeclampsia were excluded and referred to a specialty hospital for follow-up. For the present study, two additional inclusion criteria were that the participants had at least one complete dietary recall in both the second and third trimesters of pregnancy and at least two measurements of gestational weight during pregnancy.

After screening for eligibility and acquiring informed consent at either the first visit or at health clinics during recruitment, women were seen monthly over the course of their pregnancies. Information on clinical, anthropometric, and biochemical parameters and maternal diet was collected at each visit by a dedicated team including certified medical staff and a dietitian.

Maternal Diet Quality Score

A dietitian with standardized training collected data on maternal diet via a multiple-step 24-h dietary recall (24 H-DR) at each prenatal visit (median time between visits: 5 wk). The average number of dietary recalls during pregnancy was 5.8 (SD 0.87, range three to nine measurements). To evaluate diet quality, we built an MDQS based on the MDG [22] and international recommendations for specific foods and nutrients. We included the following recommendations regarding nutrients and food groups:

- polyunsaturated fats (PUFAS; >6% of energy intake) [24];
- added sugars (<10% of total energy) [25];
- fruits and vegetables (>400 g/d) [25];
- red meat (<500 g/wk) [22,26];
- low fat dairy products (2 servings/d) [22];
- legumes (2 servings/d) [22]; and
- foods high in saturated fat or added sugar (HSFAS; <10% of energy intake) [27].

A value of 1 was assigned if the recommendation was met and 0 if the recommendation was not met for each of the seven individual recommendations. The scores for each recommendation were then summed with a maximum score of 7 if all recommendations were met and a minimum of 0 if no recommendations were met. We defined three categories of adherence: low (0–2 points), medium (3–4 points), and high (≥5 points). Detailed methodology about the collection of maternal dietary data and its transformation to derive a priori and a posteriori dietary patterns and scores, and a finding that MDQS was associated with LBW in this cohort, are provided elsewhere (unpublished results, April 30, 2019).

Anthropometry

Maternal weight and height were measured at the first and consecutive visits (median time between visits: 5 wk) by trained staff using standardized methods (Lohman technique) [28]. The average number of visits and body weight measurements during pregnancy was 5.8 (SD 0.87; range 3–9 measurements); the first and the last weight measurements were carried out during gestational weeks 11 (SD 1.7 wk; range 2.4–13.6 wk) and 37 on average (SD 2.9 wk; range 25.2–45.5 wk) in the sample for this study. Prepregnancy weight was self-reported by participants. The prepregnancy BMI was calculated in kg/m^2 and was categorized into five groups: underweight (<18.5), normal (>18.5 to 24.9), overweight (25–29.9), obesity 1 (30 to 34.9), and obesity 2 (>35).

Rate of gestational weight gain (RGWG; kg/wk) was calculated at each visit throughout the whole pregnancy as weight at the current visit minus weight from the previous visit, divided by follow-up duration (g/wk). In the case of the first visit, RGWG was estimated using prepregnancy weight. We categorized RGWG according to whether Institute of Medicine (IOM) [29] recommendations were met (insufficient, adequate, and excessive) based on ranges of the mother's prepregnancy BMI. The recommended weight gain in the first trimester of pregnancy (until 13 wk) is 2 kg (0.17 kg/wk) for all categories of maternal prepregnancy weight status [30]. Recommended weight gain in the second and third trimesters was based on the assumption that underweight, normal weight, overweight, and obese women should gain weight within the normal range of 0.44 to 0.58, 0.35 to 0.50, 0.23 to 0.33, and 0.17 to 0.27 kg/wk, respectively [29]. We did not use the total weight gain as an outcome because the timing of the final measurement of weight gain varied between the mothers; that is, the monitoring of maternal weight gain ended at different time points depending on when in gestation the mother made her last clinic visit before giving birth.

Potential confounders

Maternal age, education, and parity (number of pregnancies reported) were obtained using questionnaires that collected data on sociodemographic variables, obstetric history, and detailed information about the pregnancy. Maternal education was grouped by whether the mother completed 9 y of school (≥9 y or <9 y). Parity was divided into three groups (nulliparous, 1–2, and ≥3). Marital status was divided into two groups (married/partnered or divorced/single). Physical activity was assessed in each visit and categorized into whether the women met or did not meet the American College of Obstetricians and Gynecologists recommendations (≥150 versus <150 min/wk) [31].

Statistical analysis

Maternal characteristics

Descriptive statistics were computed for sociodemographic variables and maternal characteristics. Differences between sociodemographic variables were compared using Fisher exact test and analysis of variance for categorical and continuous variables, respectively. Differences were considered significant at a significance level of $P < 0.05$.

Gestational weight gain trajectories

Appropriate modeling of longitudinal GWG patterns is essential to assess associations between this maternal variable and different exposures or outcomes, but it also represents several statistical challenges [32]. Linear spline regression models have recently been proposed as a method of representing change, which reduces the dimensionality of repeated measurements [33]. The shape of the trajectory of change is assumed to be piecewise linear, with knot points defining changes in the magnitude or direction of association of the response variable with time [33]. The selection of the number and location of knot points may be determined by the data or by prior knowledge to allow the linear splines to represent the shape of the change trajectory in a meaningful way [33].

In the present sample, individual trajectories of RGWG (based on mother's weight measurements at visit, without estimating fetal weight) were modeled in a multilevel linear spline regression framework (measurement occasion at level 1; individuals at level 2). We used the methodology proposed by Howe et al. [32], which has been applied totally or partially in various epidemiologic studies [33–38]. The shape of the trajectory was specified as a linear spline with 3 knots at 20, 30, and 40 wk of gestation. The knots were placed to best reflect the observed data. Correlation between weight measurements within an individual was modeled by including random effects for the intercept and slope (for weeks of gestation) into the model. No additional correlation structure was assumed for the error terms. Subsequently, trajectories were smoothed using the "loess" option in ggplot2, a package in R, with a span value of 0.7.

Association between MDQS and weight gain trajectories

We performed linear splines mixed-effect (LSME) regression models to evaluate the association between MDQS during pregnancy and RGWG trajectories from first to last visit. Gestational age (weeks) was included in LSME models as a random and fixed effect to adjust for the overall and individual variations in the RGWG over time and according to MDQS categories. All other covariates (gestational prepregnancy BMI, maternal age, educational level, parity, fetal sex, marital status, and physical activity) were included as fixed effects. The principal advantages of using piecewise linear models are that they make it easier to approximate smooth curves compared with quadratic models and that they have a more straightforward interpretation when evaluating the relationship between covariates and trajectories [39].

By using splines in modeling, we allowed MDQS exposure to affect all four slopes, one for each of the four segments of the spline. Thus, the effects on the difference in RGWG at early-mid pregnancy (0–20 wk), middle pregnancy (≥20 and <30 wk), late pregnancy (30–40 wk) and prolonged pregnancy (≥40 wk of gestation), comparing high and medium adherence to MDQS against the category of reference (low adherence), were assessed. No additional correlation structure was assumed for the error terms. We adjusted for the variables as other covariates; additionally, we adjusted the models by energy intake (kcal/d) because we were interested in the effect of diet quality independent of total energy intake.

In addition, we implemented mixed-effect logistic regression models to explore the influence of the MDQS on the excessive or inadequate RGWG categories during pregnancy. These models were stratified by prepregnancy BMI categories and further adjusted for the confounders listed as other covariates.

All models included measurements of MDQS and RGWG obtained from each visit.

Sensitivity analyses

We repeated the analyses of mixed-effect logistic regression models including only women for whom the number of total prenatal visits was five or more. We evaluated the associations separately in women with a prepregnancy BMI below or above the cutoff point of 25 kg/m^2. Moreover, we compared the models using a prepregnancy BMI calculated from the self-reported pregestational weight and the BMI calculated from the weight obtained in visit 1 in women whose first measurement was carried out before week 14 (n = 230).

All statistical analyses were performed in Stata for Mac 12.1 (Drive East College; EU), R version 3.4.3 (R Foundation for Statistical Computing, Vienna, Austria) and the R package ggplot2, version 2.2.1.

Results

Baseline characteristics of the study population (N = 660) are listed in Table 1.

MDQS ranged from 0 (*no adherence at all*) to 7 (*maximum adherence*). Mean (±SD) of MDQS was 2.86 (±1.08) for first, 3.06 (±1.25) for second, and 3.30 (±1.27) for third trimester and 3.11 (±2.19) for the whole pregnancy (averaged over the three trimesters). Mean (±SD) age was 25 y (±5.8). On average, pregnant women with greater adherence (>5 points) to MDQS were older (25.8 ± 6.7 versus 24 ± 5.2 y; $P < 0.05$) and more educated (>9 y of schooling, 15.7% versus 12.7%; $P < 0.05$) compared with women with lower adherence (<3 points). We did not observe significant differences in the other baseline characteristics across the categories of MDQS.

With respect to categories of RGWG, we found differences for maternal height ($P < 0.05$), prepregnancy BMI ($P < 0.001$), and parity ($P < 0.05$). We did not find differences for age, maternal education, or baby's sex (Table 1).

Gestational weight gain

The mean (±SD) maternal prepregnancy BMI was 25.72 kg/m^2 (±5.23). About 17.42% of the participants were obese, 32.58% were overweight, and 4.49% were underweight. As to GWG, only 29.70% of women were compliant with the RGWG level recommended by IOM; 29.39% of women gained less than the recommended level, and 40.91% of participants gained more than the recommendation.

Particularly, women with prepregnancy BMI <18. and >25 kg/m^2 did not experience the recommended RGWG during second and third trimesters; 58.62% of underweight women had a lower RGWG and 58.60% of overweight women had higher RGWG than the IOM recommendation (Fig. 1).

Table 1
Sociodemographic and maternal characteristics*

Characteristic	Inadequate RGWGN = 196 (29.70%)	Adequate RGWGN = 194 (29.39%)	Excessive RGWGN = 270 (40.91%)	*P*-value
Maternal age, years (±SD)	25.72 (5.89)	24.83 (5.76)	24.89 (5.76)	0.203
Prepregnancy BMI, kg/m^2 (±SD)†	25.59 (6.10)	24.17 (4.56)	26.91 (5.23)	<0.001†
Prepregnancy BMI categories (kg/m^2), n (%)†				
<18.5	17 (8.67)	8 (4.12)	4 (1.48)	<0.001†
≥18.5 <25	98 (50.00)	124 (63.92)	79 (29.26)	<0.001†
≥25 <30	48 (24.49)	41 (21.13)	126 (46.67)	<0.001†
≥30	33 (16.84)	21 (10.82)	61 (22.59)	0.120
Term of gestation, n (%)				
Preterm	20 (10.58)	18 (9.52)	27 (10.07)	0.949
Term	169 (89.42)	171 (90.48)	241 (89.93)	0.948
Parity, n (%)‡				
Nulliparous	73 (37.24)	90 (46.88)	154 (56.30)	<0.001†
1–2	64 (32.65)	58 (30.21)	65 (24.44)	0.078
≥3	57 (29.58)	44 (22.92)	53 (19.26)	0.013†
Marital status§				
Single or divorced	48 (24.49)	41 (21.13)	81 (30)	0.163
Married/partnered	148 (75.51)	151 (77.84)	189 (70)	0.164
Educational level, n (%)				
≤9 y	117 (59.69)	109 (56.19)	144 (53.33)	0.199
>9 y	79 (40.31)	85 (43.81)	126 (46.67)	0.195
Baby sex, n (%)‖				0.499
Female	90 (45.91)	80 (41.23)	121 (44.81)	0.725
Male	90 (45.91)	104 (53.60)	131 (48.51)	0.725

BMI, body mass index; RGWG, rate of gestational weight gain rate.
*Values are n (%) or means ± SDs.
†Significantly different ($P < 0.05$) between categories of RGWG (kg/wk) during second and third trimesters defined according to Institute of Medicine recommendations [29]. *P*-value refers to Fisher exact test and analysis of variance for proportions and continuous variables, respectively.
‡One missing value in inadequate RGWG category.
§Two missing values in adequate RGWG category.
‖16, 10, and 18 missing values in Inadequate, Adequate, and Excessive RGWG categories, respectively.

Gestational weight gain trajectories

The average RGWG differed across trimesters ($P < 0.001$), with the lowest rate in the first (0.07; 95% CI, −0.59 to 1.10 kg/wk] and the highest in the second (0.26; 95% CI, −0.59 to 1.10 kg/week) and third (0.39; 95% CI, −0.40 to 1.12 kg/wk) trimesters. Figure 2 shows the average trajectory of the GWG across pregnancy predicted by the LSME regression modeling in the total sample (N = 660); the sigmoidal shape reflected that the majority of weight is gained in the second and early third trimesters of pregnancy.

Figure 3 shows the GWG trajectories according to prepregnancy BMI category predicted by LSME. The GWG patterns of women with prepregnancy BMI of ≥30 kg/m^2 had a slower RGWG than women in the other prepregnancy BMI categories. There was no

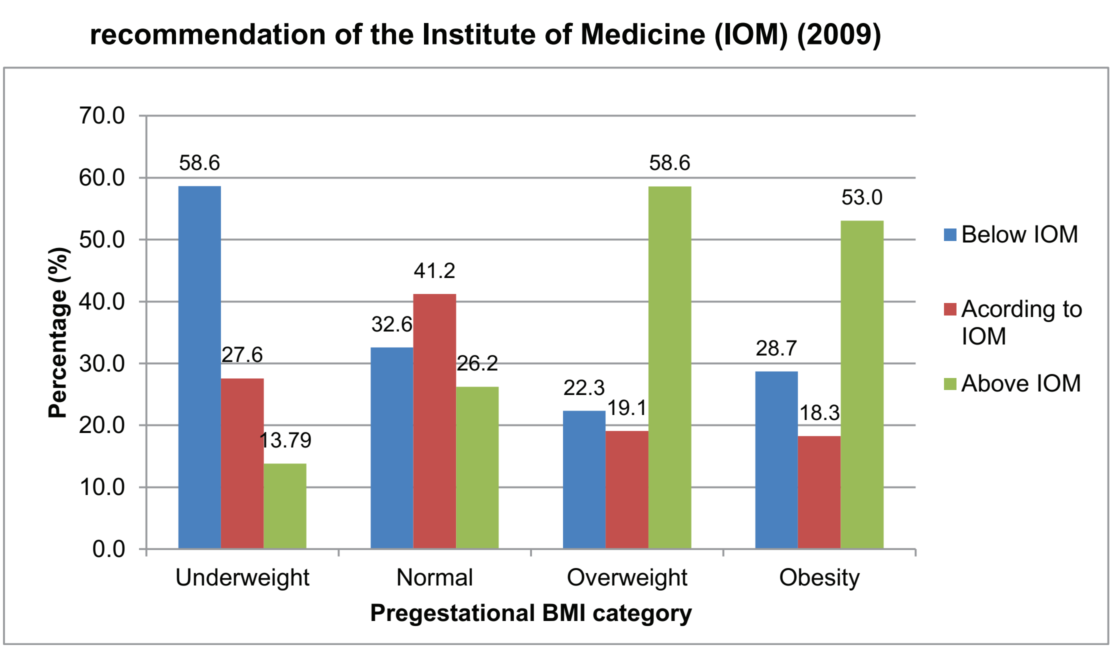

Fig. 1. Rate of gestational weight gain adequacy according to the recommendation of the IOM (2009). Values are in percentages. An adequate gestational weight gain rate (kg/wk) during second and third trimesters was defined according to the IOM recommendations [29]. BMI, body ams index; IOM, Institute of Medicine.

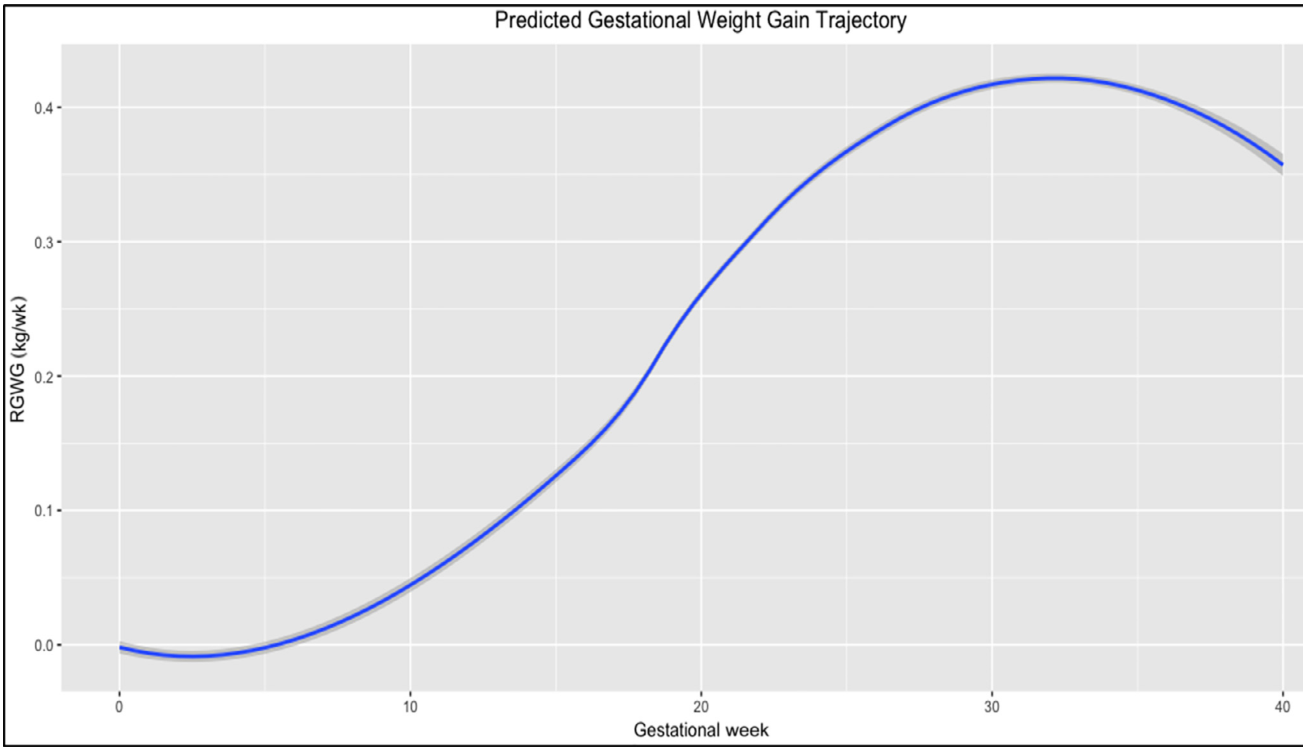

Fig. 2. Trajectory of rate of gestational weight in the study sample (N = 660). The trajectory of the RGWG during pregnancy as estimated by the linear mixed regression model. Adjusted for gestational age, maternal age, educational level, parity, pregestational BMI, physical activity, and fetal sex. BMI, body mass index; RGWG, rate of gestational weight gain.

significant difference between trajectories of women with underweight or normal prepregnancy BMI.

Association between MDQS and GWG trajectories

We found that MDQS was associated with the trajectories of RGWG across pregnancy after adjustment for potential confounders (Supplementary Table 1).

Medium and high categories of MDQS (compared with low adherence) were positively associated with the RGWG in early-mid gestation, but only the medium adherence category was statistically significant (β, 0.0162; 95% CI, 0.0005–0.0333; $P = 0.058$). Medium and high adherence categories were negatively associated with the RGWG in the middle stage of pregnancy (β, −0.0266; 95% CI, −0.0496 to −0.0037; $P = 0.023$; β, −0.0363; 95% CI, −0.076 to 0.037; $P = 0.076$ [marginally significant]). In late pregnancy, both categories of adherence were positively related (β, 0.0256; 95% CI, 0.0077–0.0436; $P = 0.005$; β, 0.0472; 95% CI, 0.0222–0.0723; $P < 0.001$). In prolonged pregnancy, medium and high adherence categories were negatively associated, but only the category of high adherence was significantly associated with the RGWG (β, −0.182; 95% CI, −0.360 to −0.0045; $P = 0.044$). Table 2 shows the crude and adjusted models.

In other words, a better diet quality during pregnancy was associated with a faster RGWG in early-mid pregnancy (0–20 wk), with a slower RGWG in the middle pregnancy (>20 and <30 wk gestation), with a speedier weight gain in late pregnancy (30–40 wk), and with a slower RGWG in women with a prolonged pregnancy (>40 wk).

With respect to the mixed-effect logistic regression models, we found that medium and high adherence to MDQS throughout pregnancy were each protective against an inadequate GWG (OR, 0.74; 95% CI, 0.56–0.99; $P = 0.04$; OR, 0.63; 95% CI, 0.42–0.95; $P = 0.03$), respectively, and an excessive GWG (OR, 0.77; 95% CI, 0.57–1.04; $P = 0.09$; OR, 0.62; 95% CI, 0.41–0.94; $P = 0.03$), respectively. The association between the medium category of adherence and an excessive GWG was only marginally significant. Table 3 shows the crude and adjusted models.

Sensitivity analyses

After repeating analyses in those women who attended more than five and six prenatal visits, we observed that the association between MDQS and the inadequate or excessive GWG remained significant. In addition, the association between the medium category of adherence and excessive GWG became statistically significant (OR, 0.31; 95% CI, 0.13–0.74; $P = 0.008$) (Supplementary Table 2). We found that higher MDQS adherence was protective against inadequate or excessive GWG, independently if women entered pregnancy with a BMI <25 or >25 kg/m^2 (Table 4).

The results of the mixed-effect logistic regression did not change greatly when comparing the models with the inclusion of prepregnancy BMI calculated from the self-reported pregestational weight versus the BMI calculated from the weight obtained in visit 1 (Supplementary Table 3).

Discussion

In this sample of pregnant women from the PRINCESA cohort, higher adherence to maternal dietary quality recommendations was protective against both inadequate and excessive GWG throughout pregnancy. These results are consistent with findings from the study carried out by Hillesund et al., which reported that normal weight women with high versus low New Nordic Diet score adherence had lower adjusted odds of excessive GWG (OR, 0.93; 95% CI, 0.87–0.99; $P = 0.024$) [19]. On the other hand, the only other study [18] that has evaluated GWG as a longitudinal outcome concluded that a priori

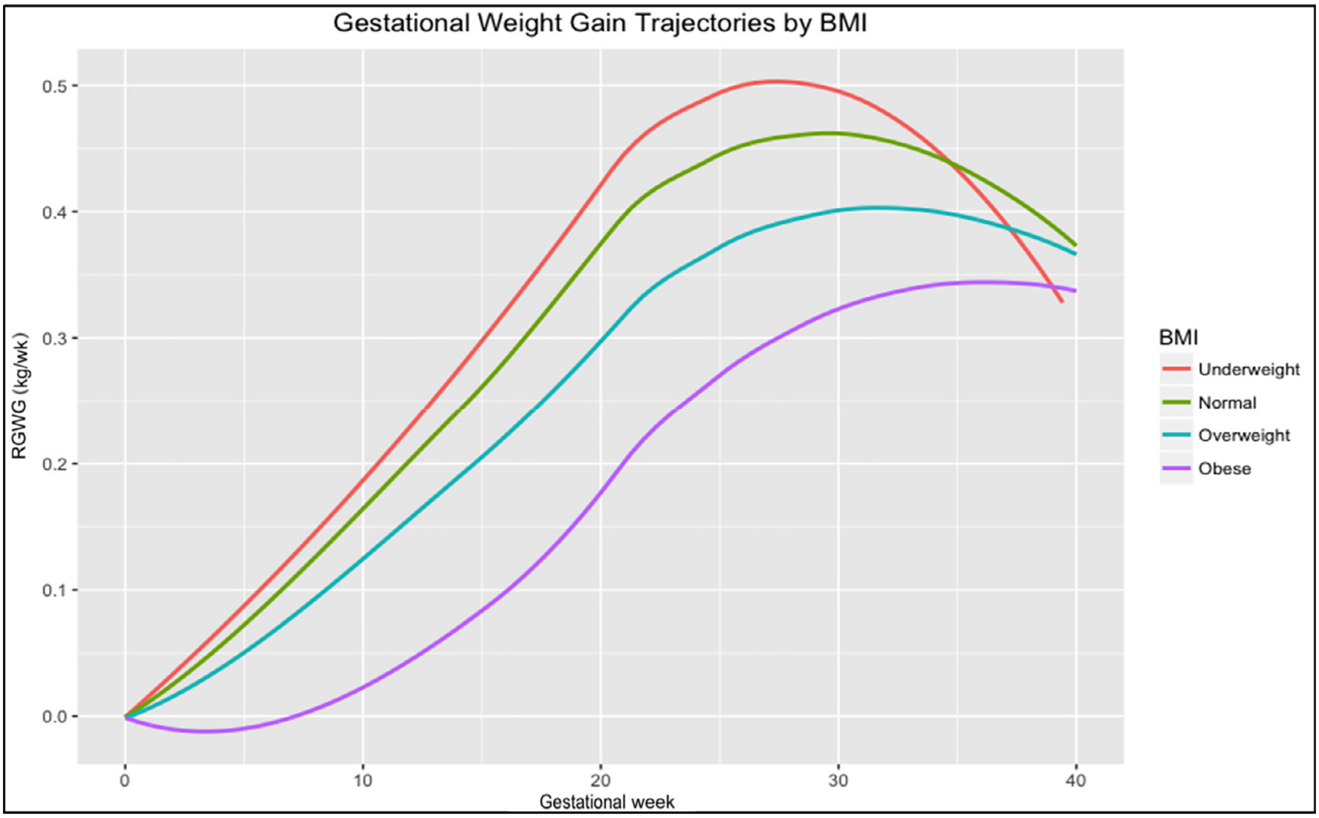

Fig. 3. Trajectories of RGWG by BMI category (N = 660). The figure shows the trajectories of the RGWG during pregnancy by category of BMI estimated by the linear mixed regression model and adjusted for gestational age, maternal age, educational level, parity, fetal sex, marital status, and physical activity. BMI, body mass index; RGWG, rate of gestational weight gain.

defined dietary patterns (Dutch Healthy Diet Index) were not consistently associated with any measure of GWG.

Results from cross-sectional studies that have evaluated the same association differ from our findings. For example, the US HEI-2005 [21] and the AHEI-P [20] were not associated with GWG. However, the epidemiologic design of these studies limits the comparison of results because the RGWG is not stable across pregnancy.

The very limited amount of literature on this topic suggests that further investigation is warranted and that attention should be paid to standardizing, if possible, the measures used and the timing for taking them to facilitate comparisons. The inconsistent associations between a priori–defined dietary patterns and GWG reported in the few previous studies may be due to the use of different food groups and cutoff points to define score weights and the timing for assessment of maternal diet or GWG.

Assessing the timing of weight gain in pregnancy is important because weight gain at key points during pregnancy has been associated with some adverse pregnancy and birth outcomes. For example, midgestational weight gain was associated with birth weight and neonatal adiposity [40]. GWG in early and late

Table 2
Association between MDQS and RGWG with spline knots at each period of pregnancy (N = 660)

		Crude model*		Adjusted model†	
RGWG at each period	MDQS adherence	β (95% CI)	*P*-value	β (95% CI)	*P*- value
Early mid pregnancy (0–20 wk)	Low	Ref		Ref	
	Medium	0.011 (0.0021 to 0.0209)	0.017	0.0162 (−0.0005 to 0.0333)	0.058
	High	0.01281 (−0.0048 to 0.0305)	0.156	0.0164 (−0.0148 to 0.0477)	0.302
Middle pregnancy (20–30 wk)	Low	Ref		Ref	
	Medium	−0.0206 (−0.0359 to −0.0053)	0.008	−0.0266 (−0.0496 to −0.0037)	0.023
	High	−0.0316 (−0.0576 to −0.0056)	0.017	−0.0363 (−0.076 to 0.0037)	0.076
Late pregnancy (30–40 wk)	Low	Ref		Ref	
	Medium	0.0229 (0.0054 to 0.0404)	0.010	0.0256 (0.0077 to 0.0436)	0.005
	High	0.0462 (0.02193 to 0.0704)	<0.001	0.0472 (0.0222 to 0.0723)	<0.001
Prolonged pregnancy (>40 wk)	Low	Ref		Ref	
	Medium	−0.0740 (−0.2513 to 0.1033)	0.413	−0.0747 (−0.257 to 0.107)	0.422
	High	−0.1587 (−0.341 to 0.2406)	0.089	−0.182 (−0.360 to −0.00450)	0.044

BMI, body mass index; MDQS, Maternal Dietary Quality Score; RGWG, rate of gestational weight gain.
Low adherence to MDQS is the reference (Ref) category for diet, and adequate RGWG is the reference category for adequacy of GWG in the logistic multilevel model
*Adjusted for gestational age.
†Models adjusted for prepregnancy BMI, energy intake, gestational age, maternal age, educational level, parity, fetal sex, marital status, and physical activity.

Table 3
Association of MDQS with inadequate and excessive RWGW during pregnancy

MDQS adherence	Inadequate RGW				Adequate RGW	Excessive RGW			
	Crude model* OR (95% CI)	*P*-value	Adjusted model † OR (95% CI)	*P*-value		Crude model* OR (95% CI)	*P*-value	Adjusted mode† lOR (95% CI)	*P*-value
Low adherence	Ref.		Ref.		Ref.	Ref.		Ref.	
Medium adherence	0.834 (0.653–1.065)	0.146	0.742 (0.555–0.991)	0.044	Ref.	0.845 (0.649–1.100)	0.212	0.773 (0.572–1.044)	0.094
High adherence	0.765 (0.534–1.095)	0.143	0.630 (0.417–0.953)	0.031	Ref.	0.698 (0.479–1.018)	0.062	0.623 (0.411–0.942)	0.025

BMI, body mass index; MDQS, Maternal Dietary Quality Score; RGWG, rate of gestational weight gain.
Low adherence to MDQS is the reference (Ref.) category for diet and adequate RGWG is the reference category for adequacy of GWG in the logistic multilevel model.
*Adjusted for gestational age.
†Models adjusted for prepregnancy BMI, energy intake, gestational age, maternal age, educational level, parity, fetal sex, marital status, and physical activity.

pregnancy was associated with gestational diabetes, gestational hypertension, macrosomia, and primary cesarean delivery [41]. Early GWG was additionally associated with pregnancy-induced hypertension, and the RGWG in late pregnancy was also associated with preterm birth [41]. Our longitudinal analysis showed that higher adherence to MDQS was associated with slower weight gain in middle and prolonged late pregnancy and with a faster GWG in the early and late pregnancy. Further analyses to assess if these patterns are associated with clinical and birth outcomes are planned.

An important finding in the present study is that a large proportion of the women had a RWGW below or above the recommended ranges. Indeed, adherence to these recommendations has been reported as suboptimal in other populations in the last systematic review and meta-analysis of this topic [42]. Specifically, we found that 40.91% of participants gained weight at a rate greater than that recommended, similar to the percentages reported by previous studies carried out in Mexican (38%) [43] and Mexican-American women (45%) [44].

Strengths

The principal strengths of the present study included the prospective design that provided a valuable opportunity to assess maternal diet and GWG in a parallel approach during different stages of pregnancy. The MDQS was calculated using food components based on the MDG [23] and international recommendations, so this score could be a useful tool for evaluating overall diet quality of pregnant women who live in similar contexts.

In general, various studies have reported that women who follow healthy dietary patterns are more likely to be older, married, and participate in more regular physical activity, suggesting that healthy food choices are part of a larger healthy lifestyle pattern [19,20,45]. Hence, another advantage of the present study was the availability of detailed information about potential confounders including maternal and sociodemographic variables.

Limitations

BMI classification should be based on prepregnancy weight; nevertheless, we did not find great differences in the estimations when comparing models that included the prepregnancy BMI calculated from the self-reported pregestational weight versus the BMI calculated from the weight obtained in visit 1 (for women whose first measurement was carried out before week 14). Also, we were not able to use the total GWG as an outcome because the final weight measurement was not provided at the same point in gestation for all the women.

Another limitation was the inability to obtain the different components of the weight gain, which includes both the mother's weight gain and the growth of the fetus and other indicators of interstitial volume expansion (swelling or edema). However, the mother's weight gain across pregnancy largely reflects fat gain, so the lack of detailed measures on the components is not likely to cause bias. Furthermore, the relative weight contributed by the growth of the fetus, uterus, placenta, and other maternal components will not be as pronounced up until gestational week 20 compared with later in pregnancy [29].

The lack of weight measurement at each visit can be also considered a limitation because fluid retention (swelling or edema) can affect the accuracy of weight measurements. However, swelling is expected in all pregnant women. Women with preeclampsia and other complicating conditions, which exacerbate this clinical symptom, were excluded from the PRINCESA cohort, so it is unlikely that extremely different degrees of edema at each visit based on these underlying conditions are present in this study.

With respect to MDQS, as in any dietary study, recall bias and other biases related to a priori dietary pattern specification (food grouping, data treatment, plausible limits, and validity) could have occurred. A limitation of using one 24-h recall at each visit, without repeated measures in consecutive days was that we could not capture the day-to-day variability in dietary intake, and therefore our measurement was subject to large within-person random error.

Table 4
Association of MDQS with inadequate and excessive RWGW during pregnancy in women with a prepregnancy BMI <25 and >25 kg/m^2

PrepregnancyBMI	MDQS adherence	Inadequate RGW		Adequate RGW	Excessive RGW	
		Adjusted model† OR (95% CI)	*P*-value		Adjusted model † OR (95% CI)	*P*-value
<25 kg/m^2	Low adherence	Ref.		Ref.	Ref.	
	Medium adherence	0.426 (0.184–0.985)	0.046	Ref.	0.347 (0.126–0.952)	0.040
	High adherence	0.295 (0.092–0.946)	0.040	Ref.	0.242 (0.059–0.989)	0.048
≥ 25 kg/m^2	Low adherence	Ref.		Ref.	Ref.	
	Medium adherence	0.095 (0.010–0.906)	0.044	Ref.	0.084 (0.126–0.918)	0.042
	High adherence	0.033 (0.002–0.442)	0.010	Ref.	0.077 (0.059–0.999)	0.050

BMI, body mass index; MDQS, Maternal Dietary Quality Score; RGWG, rate of gestational weight gain Low adherence to MDQS is the reference (Ref.) category for diet and adequate RGWG is the reference category for adequacy of GWG in the logistic multilevel model.
†Models adjusted for gestational age, prepregnancy BMI, energy intake, maternal age, educational level, parity, fetal sex, marital status, and physical activity.

However, the detailed information collected through dietary recalls provides more accurate estimates than other collection methods such as food frequency questionnaires [46].

Conclusions

To our knowledge, this was the first study to simultaneously evaluate the association between maternal dietary patterns and the GWG during pregnancy. Implementation of LSME models allowed capture of the overall and individual variations in the RGWG over time, according to MDQS categories. MDQS were protective against both inadequate and excessive GWG throughout pregnancy. Our results contribute to the scarce literature on maternal dietary patterns and weight gain throughout pregnancy.

Beneficial changes in diet sustained during the entire pregnancy may prevent an inadequate or excessive GWG during pregnancy and also may confer long-term benefits for mother and offspring. All pregnant women should be encouraged to have a healthier diet during the entire pregnancy to prevent negative maternal and fetal outcomes derived from rates of GWG lower or higher than recommended at specific points of the pregnancy.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.nut.2019.02.002.

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