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ORIGINAL ARTICLE

Pre-Gestational Obesity and Gestational Weight Gain as Predictors of Childhood Obesity: PROGRESS Cohort from Mexico City

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Objective. To evaluate the associations of pre-gestational body mass index (BMI) and gestational weight gain (GWG) with the risks of overweight, obesity, and adiposity in the first seven years of life in the offspring of a cohort of pregnant women.

Methods. Analysis of 751 mothers and their children participating in the PROGRESS cohort. These women were recruited in Mexico City between 2007 and 2010. Pre-gestational BMI was classified as normal, overweight, and obesity according to the WHO. GWG was calculated as the difference between the last reported pre-pregnancy weight and the pre-gestational weight and categorized as inadequate, adequate, or excessive, according to US IOM recommendations. Children's anthropometry was evaluated at 4–5 and 6–7 years of age. Adiposity was classified into three groups: normal (BMI *z*-score and waist circumference), overweight (BMI *z*-score>1), and overweight plus abdominal obesity (OW+AO). A generalized structural equation model (GSEM) was constructed to account for the temporal relationship between variables and to assess direct and indirect effects.

Results. A total of 49.3% of the women had excessive (13.8 ± 4.2 kg) and 19.8% inadequate (3.15 ± 3.4 kg) GWG. Women with pre-gestational overweight or obesity were more likely to have excessive GWG (OR 1.9 [95% CI: 1.32, 2.74] and 3.50 [95% CI: 1.83, 6.69], respectively). In the GSEM, excessive GWG was directly associated with OW+AO at 4–5 years. At 6–7 years, pre-gestational obesity was associated with OW+AO.

Conclusion. Pre-gestational obesity and excessive GWG were independent predictors of childhood obesity.

Key Words: Maternal obesity, Excessive gestational weight gain, Childhood obesity.

Introduction

The prevalence of overweight and obesity is increasing worldwide (1). The World Health Organization (WHO) estimated that in 2014, 41 million children under the age of five had overweight or obesity (2). In Mexico, the prevalence of overweight in children under five years of age increased by 24% from 1988–2012. In school children, the combined prevalence of overweight and obesity went from 26.9% in 1999–34.8% in 2006, remained similar between 2012 (33.2%) and 2016 (34.4%), and increased slightly in 2021 (37.4%) (3,4).

The role of maternal pre-pregnancy and pregnancy weight has been associated with the development of childhood overweight or obesity (5). In addition, excessive weight gain in women during pregnancy is associated with

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childhood obesity (6). This is important because gestational weight gain (GWG) is a modifiable factor. The United States Institute of Medicine (IOM) has issued recommendations on optimal GWG, considering pre-gestational body mass index (BMI) to reduce prenatal complications, mainly low birth weight and macrosomia (7). The study of GWG is important for two reasons: a) 47% of women have a GWG above the recommended value (8); and b) excessive GWG, even in women with normal pre-gestational weight, has been associated with adverse outcomes in both mother and child, neonatal complications, children born with significant weight for gestational age (9,10), and childhood obesity (11,12).

In issuing its recommendations in 2009, the IOM concluded that there was little evidence of long-term effects associated with GWG, including offspring adiposity during childhood. Since then, several studies have examined the relationship between GWG and various health outcomes in children at different stages of life. A meta-analysis that included data from 12 studies and 247,470 pregnancies (13) found that children born to women with excessive GWG had an increased risk of obesity at five years (relative risk [RR] 1.91; 95% CI: 1.21–3.02). However, these results come exclusively from high-income countries (the United States, Australia, Germany, and the United Kingdom). At the same time, the prevalence of obesity has increased more rapidly in low- and middle-income countries (14). Because of the magnitude of the current obesity burden in Mexico and its health consequences, it is necessary to explore the windows of opportunity to prevent this excessive weight gain at different stages of life. Therefore, the goal of this study is to evaluate the association of pre-pregnancy BMI and GWG with the risk of developing overweight, obesity, and adiposity during the first seven years of life in the offspring of a cohort of pregnant women in Mexico.

Methods

Study Sample

The study sample consisted of pregnant women and their children enrolled in the Programming Research in Obesity, Growth, Environment and Social Stressors (PROGRESS) cohort study, conducted by the National Institute of Public Health (Mexico) and the Mount Sinai School of Medicine (USA), in collaboration with the National Institute of Perinatology (Mexico). Women were recruited before their 20th week of pregnancy in four family medicine clinics from the Mexican Social Security System (IMSS) in Mexico City between 2007 and 2010. The inclusion criteria of the cohort were a) pregnancy of no more than 20 weeks gestation and b) no previous diagnosis of any of the following pathologies: diabetes mellitus, hypertension; renal, cardiac, or hepatic disease; epilepsy requiring medication; use of corticosteroids, or multiple pregnancy. Details of the study design and inclusion and exclusion criteria have been published previously (15). The study was approved by the Commission of Ethics in Research, Biosafety, and Research of the National Institute of Public Health (GCO-12-1417; Add CI: 560), the Mount Sinai School of Medicine, and the National Institute of Perinatology. In this ongoing cohort, women signed a written consent form at each visit after trained staff explained the study, and children gave their consent starting at age seven.

There were 948 mother-child pairs in the cohort study. For this analysis, who did not self-report pre-pregnancy weight, gestational week information, and/or measured weight in the third trimester of pregnancy (n = 154) and who developed gestational diabetes or pre-eclampsia (n = 39) were excluded, resulting in an analytical sample of 751 pregnant women.

Study Measurements

Maternal weight and height were measured at research visits in the second and third trimesters of pregnancy. Weight and height were measured using a BAME stadiometer with an accuracy of 100 g for weight and 0.5 cm for height. GWG was defined as the difference between the last weight recorded in the third trimester of pregnancy and the adjusted pre-gestational weight (described below). Because the timing of the third trimester measurements varied from woman to woman, the average weekly GWG was used. According to the US IOM recommendations, weight gain was considered "adequate" if the pre-gestational BMI range was 0.44–0.58 kg/wk (BMI <18.5), 0.35–0.50 kg/wk (BMI 18.5–24.9), 0.23–0.33 kg/wk (BMI 25.0–29.9), and 0.17–0.27 kg/wk (BMI ≥30.0); weight gain was considered "inadequate" if it was below this BMI range, and "excessive" if it was above this BMI range (7).

Mothers self-reported their pre-pregnancy weight at enrollment. The main disadvantage of this variable is that it could be biased in some cases, as it has been documented that weight reporting varies with BMI, which could lead to poor exposure classification (inadequate, adequate, or excessive GWG). To correct for this potential classification error, an adjustment to predict women's weight (called adjusted pre-gestational weight) was used for this analysis from the reported data of pre-gestational weight. This adjustment was obtained by estimating the direction and magnitude of the difference between self-reported weight and measured weight using information from 3,452 women aged 18–49 years who participated in the 2009 National Household Living Standards Survey (ENNVIH-3 in Spanish) (2009–2012). Details of the adjustment have been published elsewhere (16).

Trained medical personnel measured children's weight and height/length using a professional digital scale (Health O Meter, McCook, IL) at the research facilities during study visits at the following times: birth, 1, 6, 12, 24 months, 4–5 years, and 6–7 years. Waist circumference at 4–5 and 6–7 years was measured with a SECA measuring tape with millimeter precision. According to conventional international standards, all measurements were performed twice to confirm accuracy using standardized anthropometry protocols. The body mass index *z*-scores (BMI*z*) were calculated considering plausible values between –5.0 and +5.0 BMI*z* points. Children aged 4–5 years were classified as overweight or obese if their BMI*z* was above two standard deviations from the WHO reference population average. At 6–7 years, children were classified as overweight if the BMI*z* was above 1–<2 standard deviations above the reference population and with obesity if ≥2 deviations (17). Waist circumference measurements were used to assess abdominal obesity and were classified as normal if the percentile for age and sex was <90, and as abdominal obesity if it was ≥90 percentile for the Mexican population (18).

For this analysis, adiposity was a combined concept of BMI and waist circumference to classify children with higher BMI and greater abdominal adiposity, because even when BMI has high specificity, the sensitivity to detect excess fat is low (19). This classification was based on established cut points. Thus, the adiposity variable was built, and three groups were created: a) Normal –children with normal BMI*z* and normal waist circumference; b) Overweight –children who are above normal in one of these measurements; and c) Overweight plus abdominal obesity (OW+AO) –children with overweight or obesity according to the BMI*z* plus abdominal obesity.

During the second trimester prenatal visit, a questionnaire was used to collect information on the mother's sociodemographic characteristics: age (years), schooling (years), parity, and household characteristics. At birth, mode of delivery (vaginal or caesarean) and sex were recorded. In addition, information about breastfeeding practices, (classified as exclusive breastfeeding [BF], partial BF, and formula feeding) and the timing of complementary feeding (early, if the child received foods other than breast milk before four months of age and adequate, if the timing was ≥4 months of age) was collected during visits at one and six months after birth. The children's diets were evaluated using a food frequency questionnaire (FFQ) that collected information on foods consumed seven days before the visit at ages 12 and 24 months, 4–5 years, and 6–7 years. The variable used for diet was the energy consumed per day (kcal/d) at each measurement period. To measure physical activity at ages 4–5 and 6–7 years, an ActiGraph GT3X model accelerometer was placed on the children's non-dominant hand for seven days (including at least one weekend day). Minutes of moderate or vigorous physical activity were classified as <60 min/d, 60–120 min/d, and ≥120 min/d. Details of the physical activity classification methodology have been published elsewhere (20). Socioeconomic status (SES) was constructed according to the Mexican Association of Market Intelligence and Public Opinion Agencies (AMAI, version 2007). Moreover, 13 variables on asset ownership, housing conditions, and education were used to classify the study sample into low, medium, and high categories.

Statistical Analysis

An attrition analysis was performed to compare the sociodemographic characteristics of women in the analytical sample with those excluded from the analysis.

An exploratory analysis was conducted to evaluate the distribution of the response variables (BMI*z* and waist circumference at 6–7 years). The response variables were highly correlated ($r = 0.83$, $p < 0.001$). Since waist circumference did not have a normal distribution, a classification based on established cut points for each variable was defined to identify children with higher BMI and greater abdominal adiposity. Differences between the three adiposity categories in children for sociodemographic characteristics were evaluated using multinomial regression models.

Simple association patterns of adiposity (in three categories) were evaluated with each main variable (e.g., pre-gestational BMI, GWG, sex, etc.). Simple regression models were adjusted for each pair of explanatory variables to evaluate their association, considering the different moments of measurement throughout the follow-up period.

The association between pre-gestational obesity, GWG, and children's adiposity was evaluated using a generalized structural equation model (GSEM). This approach was considered because although the goal is to evaluate the association of excessive GWG with adiposity in the first seven years of children's lives, it is important to recognize that, over time, there are other conditions (maternal or child) that are influenced by GWG and, in turn, influence adiposity itself. This creates direct and indirect patterns of association between GWG and adiposity. GSEMs allow the evaluation of these direct and indirect patterns. Unlike multivariate models, this approach allows analyzing complex patterns of association between all the variables included in the analysis. That is, not only the direct associations between the explanatory variables and the response variable(s), but also among the explanatory variables themselves. This allows the estimation of direct and indirect associations between the response(s). Additionally, it can consider the temporality of the measured variables and the scale of the response variable(s) (beyond the continuous case) (21).

In the GSEM, those associations with a significant trend in the sample recognized in the literature were included. The most relevant effects were identified, and the final model included those variables that directly or indirectly explained overweight and adiposity at 6–7 years of age (schooling, parity, age, pre-pregnancy BMI, sex, breastfeeding, time of complementary feeding initiation, kcal at 12 and 24 months). All analyses were performed in the statistical package STATA version 14.2 (StataCorp LP, College Station, Texas, USA, Copyright 1985–2015).

Results

The mean age of the 751 women included in the analysis was 27.1 ± 5.1 years, with 11.8 ± 2.9 years of schooling, and a pre-gestational BMI of 25.2 ± 4.0 kg/m^2 (34% were overweight and 12% had obesity). In addition, the majority of women had a partner (81.5%), were nulliparous (62.0%), and were from low SES (52.2%) (Table 1). No significant differences were observed between women included in the analysis and those excluded for all variables except for type of delivery. Among the excluded women, the proportion of cesarean births is bigger than among the women in the study sample (59.9 vs. 49.9%) because they had pre-eclampsia, which is one of the exclusion criteria (data not shown in the table).

Overall, 49.3% of women had excessive GWG (13.8 ± 4.2 kg), while 19.8% had inadequate GWG (3.15 ± 3.4 kg) (Table 2). Women with overweight or pre-gestational obesity were more likely to develop excessive GWG (OR 1.90, 95% CI: 1.32, 2.74 and OR 3.50, 95% CI: 1.83, 6.69, respectively) than women with normal pre-gestational BMI. Contrary to what was expected, it is also observed that women with pre-gestational obesity were 4.05 times more likely to have insufficient GWG (95% CI: 1.97, 8.34), a result that requires further analysis.

Children born to women with excessive GWG had, on average, higher birth weight (3.13 ± 0.43 kg) than children born to women with inadequate GWG (3.0 ± 0.41 kg), $p < 0.05$ (Table 2). No significant differences in birth weight were found when stratifying by pre-gestational BMI (data not shown in tables). Figure 1 shows the BMI*z* of children at 1, 6, 12, and 24 months and at 4–5 and 6–7 years stratified by GWG category. Children of women with excessive GWG tended to have a higher BMI*z*, starting at 24 months; however, these differences were not statistically significant.

When BMI*z* and waist circumference (as a proxy for adiposity) were analyzed together, 11.1% of children had OW, and 6.1% had OW+AO at 4–5 years (Table 3). Furthermore, more OW+AO was found in girls (8.9%) than in boys (3.2%) ($\beta = 0.36$, 95% CI: 0.15, 0.83). Similarly, children of women with excessive GWG were 2.6 times more likely to have OW+AO than those with adequate GWG (95% CI: 1.02, 6.47). In comparison, the children of women with pre-gestational obesity were 3.0 times more likely to develop this pattern than those with normal BMI (95% CI: 1.16, 7.71). For the age group 6–7 years, a similar pattern of adiposity by sex and a higher proportion of children with OW+AO was observed in women with pre-gestational obesity.

Figure 2 describes the changes in weight status for children aged 2, 4–5, and 6–7 years. At two years, 32.4% of children were overweight, of whom 22.3% were still overweight at 4–5 years, 14.9% had OW+AO and, of the latter, 66.6% remained in this category at 6–7 years. While 92.5% of children with a normal BMI*z* at age two remained in this category at 4–5, only 88.4% were still in this category at 6–7 years.

Figure 3 and Table 4 show the GSEM that evaluates the association between GWG and the child's obesity at ages 6–7. Pre-gestational obesity, excessive GWG (IRR 3.01; 95% CI: 1.16, 7.77), and child sex were directly associated

Table 1. Characteristics of women participating in the study

Measures	Women included in the analysis (*n* = 751) Mean (SD)	Pre-gestational low/normal BMI (*n* = 405, 53.9%) Mean (SD)	Pre-gestational overweight/obesity BMI (*n* = 346, 46.1%) Mean
Age (years)	27.1 (5.1)	26.2 (5.2)	28.2 (5.6)
Weight (kg)	60.6 (10.6)	53.4 (5.7)	69.2 (8.3)
Height (m)	1.55 (0.05)	1.55 (0.05)	1.55 (0.05)
Pre-gestational BMI (kg/m^2)	25.2 (4.0)	22.2 (1.8)	28.6 (3.0)
Schooling	11.8 (2.9)	11.8 (2.9)	11.9 (2.8)
Categorical variables (*n*, %)			
Marital Status			
Married/domestic partnership	612 (81.5)	319 (78.8)	293 (84.7)
Parity			
Nulliparous	466 (62.0)	233 (57.5)	233 (67.3)
Socioeconomic status			
Low	392 (52.2)	206 (50.8)	186 (53.8)
Middle	280 (37.3)	157 (38.8)	123 (35.5)
High	79 (10.5)	42 (10.4)	37 (10.7)
Smoked during pregnancy (n=609)			
No	472 (98.7)	252 (98.4)	220 (99.1)
Type of delivery			
Vaginal	376 (50.1)	228 (56.3)	148 (42.8)

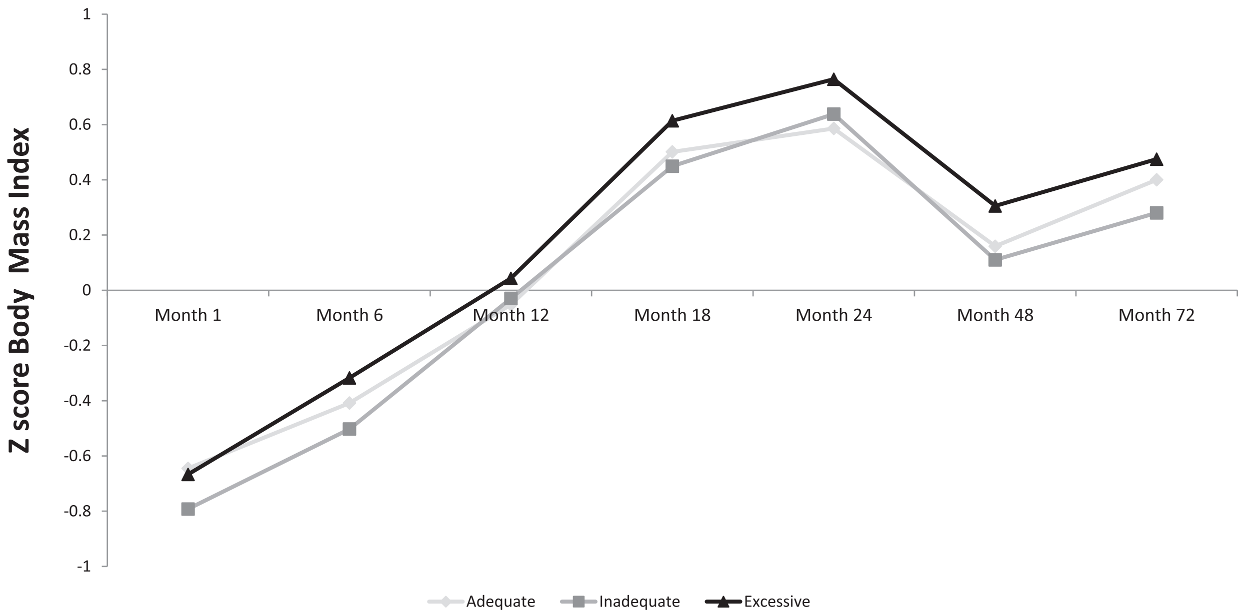

Figure 1. BMI*z* in children stratified by gestational weight gain.

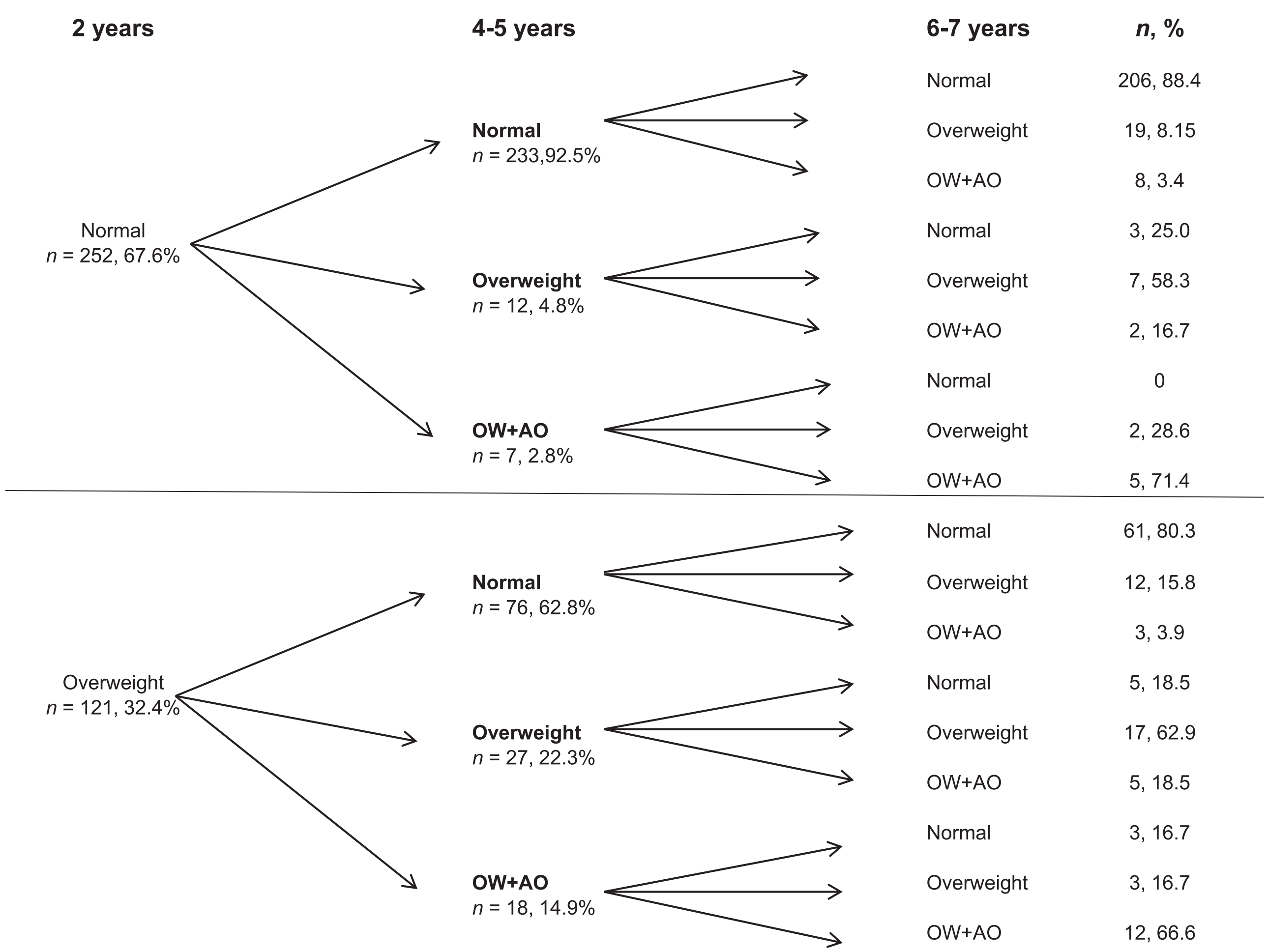

Figure 2. Changes in nutritional status in children aged 2–7 years.

Table 2. Gestational weight gain classification

	Inadequate ($n = 149$) 19.8	Adequate ($n = 232$) 30.9	Excessive ($n = 370$) 49.3	Inadequate vs. Adequate	Excessive vs. Adequate
Age group	%	%	%	OR (95% CI)	OR (95% CI)
18–24 years	20.5	31.3	48.2	1	1
25–34 years	18.8	29.8	51.4	0.93 (0.60–1.46)	1.18 (0.83–1.69)
35–44 years	22.1	33.7	44.2	0.98 (0.50–1.92)	0.89 (0.51–1.55)
Marital status					
Single/separated	21.6	30.2	48.2	1	1
Married/domestic partnership	19.4	31.1	49.5	0.88 (0.52–1.48)	1.00 (0.65–1.53)
Pre-gestational BMI					
Low weight	21.4	21.4	57.1	3.04 (0.50–18.6)	3.57 (0.75–17.1)
Normal	18.9	38.1	43.0	1	1
Overweight	18.0	26.2	55.9	1.39 (0.87–2.22)	1.90 (1.32–2.74)
Obesity	29.9	14.4	56.7	4.05 (1.97–8.34)	3.50 (1.83–6.69)
Parity					
Nulliparous	18.7	32.0	49.4	1	1
Multiparous	21.8	29.1	49.1	1.28 (0.84–1.95)	1.09 (0.78–1.54)
Socioeconomic status					
Low	20.7	31.4	48.0	1	1
Middle	19.6	30.4	50.0	0.98 (0.63–1.52)	1.08 (0.76–1.53)
High	16.5	30.4	53.2	0.82 (0.40–1.71)	1.14 (0.66–1.98)
New-born outcome					
Pre-term (<37 weeks)	8.7	7.8	11.1	1.14 (0.54–2.39)	1.48 (0.83–2.64)
Birth weight (<2500 gr)	10.1	8.2	5.9	1.25 (0.61–2.54)	0.72 (0.38–1.35)
Macrosomia (>4000 gr)	0.7	0.9	1.9	0.79 (0.07–8.83)	2.16 (0.44–10.5)
Gestational age (weeks)	38.4 ± 1.52	38.6 ± 5.8	38.4 ± 1.6		
Birth weight (kg)	3.0 ± 0.42	3.08 ± 0.42	3.13 ± 0.44*		

*$p < 0.05$ Excessive GWG vs. inadequate GWG; Logistic regression models.

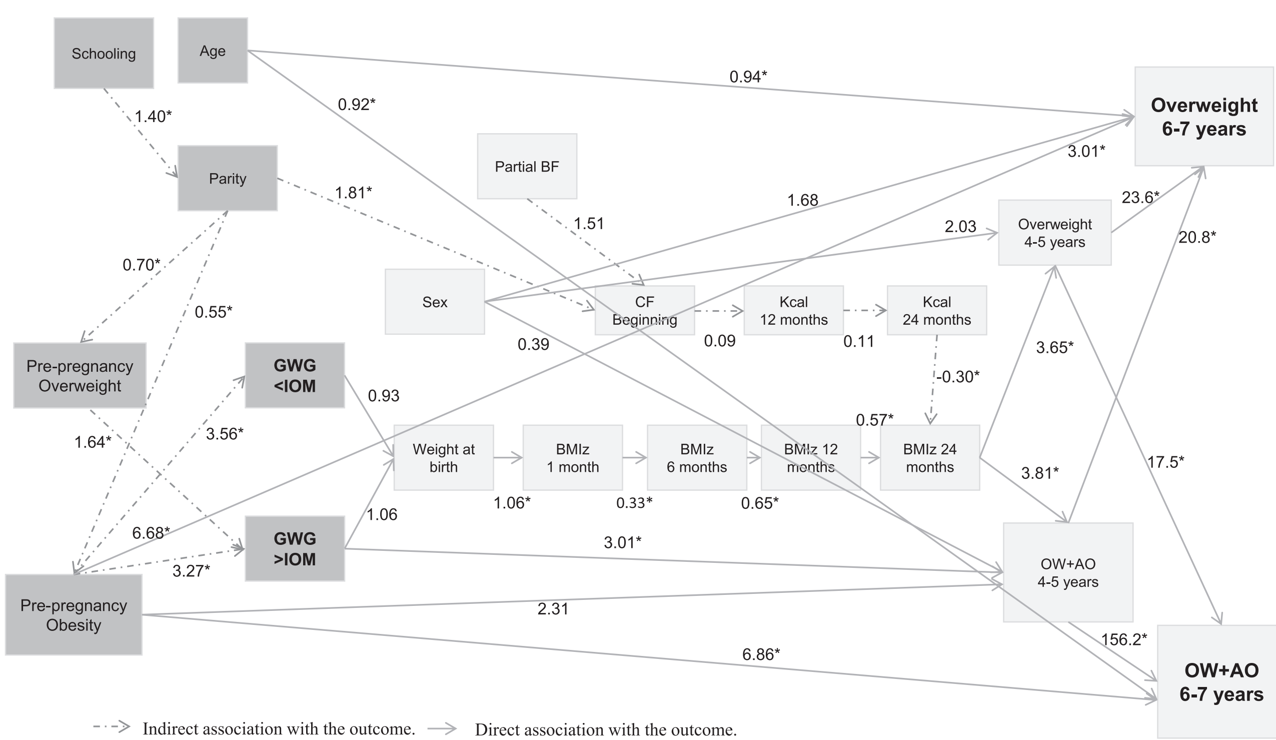

Figure 3. GSEM. Association between gestational weight gain and childhood obesity.
GWG<IOM = inadequate gestational weight gain; GWG>IOM = excessive gestational weight gain; Partial BF = Partial breastfeeding; CF Beginning = start of complementary feeding (<4 months); OW+AO Overweight and abdominal obesity. *$p < 0.05$.

Table 3. Distribution of adiposity of children at 4–5 and 6–7 years

Measures	***n***	**Adiposity of the child at 4–5 years**			***p*[a]**	**Adiposity of the child at 6–7 years**			***p*[a]**
		Normal	**Overweight**	**OW+AO**		**Normal**	**Overweight**	**OW+ AO**	
Total	505	82.8	11.1	6.1		74.0	15.9	10.1	
Sex					**0.01**				**0.03**
Girls	259	82.6	8.5	8.9		75.1	12.5	12.4	
Boys	246	82.9	13.8	3.3		73.0	19.3	7.7	
Physical activity					0.44				0.70
<60 min	100	87.0	6.0	7.0		79.5	9.6	10.8	
60 a 120 min	329	83.0	11.3	5.8		73.5	15.7	10.8	
>120 min	31	77.4	16.1	6.5		72.7	15.9	11.4	
Start of complementary feeding					0.52				0.61
≥4 months	320	83.1	10.3	6.6		73.5	16.1	10.4	
<4 months	84	80.9	14.3	4.8		71.4	20.2	8.3	
Breastfeeding					0.09				0.09
Exclusive	64	84.4	4.7	10.9		79.0	9.7	11.3	
Partial	271	81.9	12.6	5.5		71.9	18.3	9.7	
Formula	47	89.4	8.5	2.1		83.3	14.6	2.1	
Gestational weight gain					**0.02**				0.55
Adequate	161	83.2	13.0	3.7		77.5	15.0	7.5	
Inadequate	100	84.0	14.0	2.0		72.7	18.2	9.1	
Excessive	244	82.0	8.6	6.14		72.3	15.5	12.2	
Pre-gestational BMI					0.44				**0.02**
Low weight	8	87.5	12.5	0		83.3	16.7	0	
Normal	260	84.6	10.8	4.6		78.2	13.9	7.9	
Overweight	172	82.1	11.6	6.4		74.4	16.5	9.1	
Obesity	64	76.6	10.9	12.5		55.6	22.2	22.2	
Socioeconomic status					0.19				0.11
Low	264	81.4	10.6	7.9		73.3	16.5	10.1	
Middle	190	85.3	10.0	4.7		74.7	13.2	12.1	
High	51	80.4	17.7	1.9		75.5	22.4	2.0	

Boldface indicates statistical significance (p <0.05). OW+AO = Overweight plus abdominal obesity. [a] Groups comparison based on multinomial regression models.

with OW+AO in children aged 4–5. Similarly, a direct effect of excessive GWG on OW+AO at 4–5 years was observed through birthweight and BMI at one month and up to two years.

At ages 6–7, pre-gestational obesity was associated with OW alone (IRR 3.01; 95% CI: 1.34, 6.73); however, the IRR doubled when OW+AO was considered (6.86; 95% CI: 2.67, 17.6). This means that children of mothers with pre-gestational obesity are more likely to have OW+AO.

Although, in general, the variable that explains the OW and the OW+AO to a greater extent is the previous nutritional status of the child, both at 4–5 and 6–7 years. Its relevance should be taken with caution since the result is based on some observations within the categories.

In this analysis, associations reported in the literature were observed. For example, both overweight and pre-gestational obesity were associated with excessive GWG, with the effect being more significant in women with pre-gestational obesity (IRR 3.27; 95% CI: 1.72, 6.23) than in those with overweight (IRR 1.64; 95% CI: 1.19, 2.25). However, pre-gestational obesity was also associated with inadequate GWG (IRR 3.56; 95% CI: 1.76, 7.18). Finally, parity explains pre-gestational overweight and obesity and is also associated with the age of initiation of complementary feeding.

Discussion

Excessive GWG was directly associated with OW+AO in children aged 4–5 years, while pre-gestational obesity, maternal age, and child sex were associated with OW+AO in children aged 6–7.

The proportion of women with excessive GWG (49%) was similar to that reported in other studies. According to the IOM, this proportion is approximately 43% and higher in women with pre-gestational overweight or obesity (7). These findings have also been reported in other studies (22). Specifically in Mexico, Ancira et al. recently reported excessive GWG (40.9%) in a cohort of women in Mexico City (23). In this study, women with pre-gestational obesity also had inadequate GWG (29.9%). However, the authors of this study do not have information on whether the women received weight gain counseling during pregnancy.

This study found that children of women with excessive GWG weighed an average of 130 grams more at birth than children of women with inadequate GWG, regardless of pre-pregnancy BMI. In particular, Starling et al. (24)

Table 4. Generalized structural equation model

Dependent variable	Independent variables	IRR (%95 CI)
Multinomial regression models		
OW at age 6–7 years	OW at 4–5years	23.56 (11.07, 50.16)[a]
	OW+AO at 4–5 years	20.77 (4.88, 88.44)[a]
	Child's sex	1.68 (0.95, 2.95)
	Maternal age	0.94 (0.89, 0.99)
	Pre-pregnancy obesity	3.01 (1.34, 6.73)
OW+AO at age 6–7 years	OW at 4–5 years	17.49 (6.23, 49.07)[a]
	OW+AO at 4–5 years	156.2 (40.22, 606.9)[a]
	Maternal age	0.92 (0.86, 0.99)
	Pre-pregnancy obesity	6.86 (2.67, 17.62)
OW at age 4–5 years	Child's sex	2.03 (0.97, 4.21)
	BMI at 24 months	3.65 (2.41, 5.52)
OW+AO at age 4–5 years	Excessive GWG	3.01 (1.17, 7.75)
	Child's sex	0.39 (0.15, 1.01)
	BMI at 24 months	3.81 (2.32, 6.22)
	Pre-pregnancy obesity	2.31 (0.78, 6.83)
Inadequate GWG	Pre-pregnancy obesity	3.56 (1.76, 7.18)
Excessive GWG	Pre-pregnancy overweight	1.64 (1.20, 2.25)
	Pre-pregnancy obesity	3.27 (1.71, 6.23)
Pre-pregnancy overweight	Parity	0.7 (0.50, 0.96)
Pre-pregnancy obesity	Parity	0.55 (0.33, 0.90)
Logistic regression models, OR (95%IC)		
Birth weight	Inadequate GWG	0.93 (0.84, 1.01)
	Excessive GWG	1.06 (0.98, 1.13)
Complementary feeding	Partial breastfeeding	1.51 (0.89, 2.57)
	Parity	1.81 (1.15, 2.85)
Parity	Years of schooling	1.4 (1.27, 1.55)
Linear regression models, β (95% CI)		
BMIz at 1 month	Birth weight	1.06 (0.88, 1.24)
BMIz at 6 months	BMIz at 1month	0.33 (0.24, 0.43)
BMIz at 12 months	BMIz at 6 months	0.65 (0.57, 0.73)
BMIz at 24 months	BMIz at 12 months	0.57 (0.48, 0.66)
	Energy intake at 24 months	–0.3 (–0.50, –0.10)
Energy intake at 12 months	Complementary feeding	0.09 (–.002, .019)
Energy intake at 24 months	Energy intake at 12 months	0.11 (–0.03, 0.24)

[a]The magnitude should be taken with caution since it is the result of some observations for the categories; OW = Overweight; OW+AO = Overweight plus abdominal obesity, GWG= Gestational weight gain.

analyzed how the intrauterine environment influences the risk of neonatal adiposity by measuring neonatal body fat using air displacement plethysmography within the first three days after birth. The study shows that weight gain during pregnancy is positively associated with neonatal adiposity. Similarly, a meta-analysis reported that 31.6% of newborns classified as large for their gestational age could be attributed to excessive maternal GWG (25).

Regarding the association of excessive GWG with childhood obesity at age 5, the results are consistent with two studies. Ensenauer et al. (11) found an excessive GWG of 53%, an overweight prevalence in children of 10%, and a significant association of excessive GWG with childhood obesity and adiposity. Another study that analyzed BMI*z* and waist size found that children of women with excessive GWG had a higher BMI and larger waist size (28). Although the statistical approach in both studies is different, and BMI*z* and waist size are analyzed separately, similar results were observed with excessive GWG.

Previous studies have shown that excessive GWG and pre-gestational obesity are associated with childhood obesity (5). However, the age at which childhood obesity occurs is unclear. Some studies have found that children of women with excessive GWG may have obesity from an early age, <5 years, to adulthood (13,26,27). This analysis found that excessive GWG was directly associated with OW+AO at age 5 and indirectly through the child's adiposity at age 7. In contrast, maternal pre-gestational obesity was directly associated with OW+AO in children aged 5–7 years. Similarly, Josey MJ, et al. (28) observed a direct relationship between pre-gestational obesity with overweight in 4–year-old children and an indirect relationship mediated by GWG. These results suggest that the effect of pre-gestational obesity on childhood obesity has a greater scope and magnitude than that of GWG. In addition, a meta-analysis of 37 cohort studies found that children of women with pre-gestational obesity were 3.12 times more likely to develop obesity between 5 and 10 years of age.

Children of women with excessive GWG have a 1.57 times higher risk of obesity (29). Téllez-Rojo MM, et al. found that children of overweight mothers tended to have a higher caloric intake, resulting in a higher propensity for obesity (30). This may explain why pre-gestational obesity is reflected in children's weight at 4–5 and 6–7 years, rather in their birth weight.

This research is consistent with the study by Li C, et al., in which three trajectories of child growth were identified. In the group of children with normal BMI at two years, 88.4% remained in this category at seven years. This proportion is similar to that reported in this study (83.1%), while 10.9% of the children were overweight and remained so at 2, 4, and 6 years. Li C, et al. also found that child sex, maternal pre-pregnancy overweight or obesity, GWG $\geq$20.4 kg, and maternal age >30 years were associated with an increased risk of early overweight. These findings are similar to those shown in the GSEM diagram (Figure 3) regarding the association of pre-gestational obesity and excessive GWG with OW+OA in children aged 4–5 and 6–7 years (31).

In this study, parity was positively associated with pre-gestational overweight and obesity, which explained the GWG. These results are similar to those reported in the literature; for example, a study by Paulino et al, reports that multiparous women were twice more likely than nulliparous women to be obese at the beginning of their subsequent pregnancy. Higher GWG was found in nulliparous women than in multiparous women (32).

Early introduction of complementary feeding (age <4 months) (33) and increased energy intake during complementary feeding (34) have been associated with childhood obesity. This analysis found no evidence of a direct association between early complementary feeding and overweight or obesity in children aged 4–5 and 6–7 years. However, an indirect effect through energy intake and a higher *z*-score was observed in two-year-old children.

Limitations and Strengths

This study has several limitations. The study population comes from a single public health institute, which limits the generalizability of the results to women with health services in Mexico. Additionally, women with medical reports of gestational diabetes mellitus (GDM) were excluded from the cohort study. However, no screening test was used for diagnosis, so women with GDM could have been included in the study. Because the prevalence of GDM in other studies is very low (<1%), the authors considered that the results would not be affected. Another limitation is that only waist circumference was used as an indicator of body fat in the analysis. However, this has been shown to be a good indicator of body fat and a predictor of metabolic risk factors in this population (35). Finally, pre-pregnancy weight was self-reported; however, a correction procedure was implemented to reduce this bias (16).

A strength of this study is the longitudinal design used to obtain information, which allows for considerations of temporality by having data available during pregnancy and at different times of child growth. Another strength is the statistical approach which considers overweight and abdominal obesity together, and the statistical modeling, which allows the inclusion of mediating variables and the relationship between them and temporality.

Conclusion

Obesity is a complex and multifactorial problem. Studying the mechanisms associated with this epidemic during critical life-cycle periods may provide opportunities to better understand and prevent the problem. These results highlight the importance of pre-gestational obesity in the development of childhood obesity (36). According to the results, pre-gestational obesity has a more significant effect than excessive GWG on the development of childhood obesity. National and international recommendations establish that women with pre-gestational obesity should be monitored for weight gain during pregnancy. It may increase adipose tissue depots and cause greater fat transfer to the fetus (37). While these results are consistent with this recommendation, it is also important to ensure that women with normal pre-gestational BMI do not exceed GWG to avoid contributing to the risk of developing childhood obesity.

This seven-year follow-up of the offspring of a cohort of pregnant women revealed an important contribution of pre-gestational weight and GWG to the risk of childhood obesity. Given the magnitude of this problem worldwide, serious efforts are needed to establish policies and programs to change these factors into one of the lines of obesity prevention and control.

Disclosure

The authors declare that they have no actual or potential competing financial interests. Completed disclosure of interest forms are available to view online as supporting information.

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Supplementary materials

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