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Original Contribution

Maternal, Birth, and Early-Life Influences on Adult Body Size in Women

Mary Beth Terry[1], **Ying Wei**[2], **and Denise Esserman**[2,3,4]

[1] Department of Epidemiology, Mailman School of Public Health, Columbia University, New York, NY.
[2] Department of Biostatistics, Mailman School of Public Health, Columbia University, New York, NY.
[3] Department of Biostatistics, School of Public Health, University of North Carolina, Chapel Hill, NC.
[4] School of Medicine, University of North Carolina, Chapel Hill, NC.

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The authors conducted a follow-up study of 261 women born during 1959–1965 (38% White, 40% African-American, and 22% Latina) to investigate whether maternal and infant factors are independently associated with adult body size after accounting for childhood growth. Standard statistical methods (linear regression and logistic regression) were compared with quantile regression methods to assess the independent effect maternal factors (body mass index (BMI; weight (kg)/height (m)^2), maternal weight gain), birth measures (birth weight, placental weight), and early infancy and childhood growth measures (birth–4 months, 4 months–1 year, and 1–7 years) have on predicting adult body size. While most of these factors were important predictors of BMI at age 20 years, the size and relative importance of the effect differed across models. For example, maternal weight gain was associated with being overweight (BMI $\geq$ 25) at age 20 years (per 10-pound (4.5-kg) change, odds ratio = 1.65, 95% confidence interval: 1.11, 2.44) and was associated with the upper quantiles ($\geq$75th percentile) of BMI at age 20 years. In contrast, maternal BMI and birth weight were relatively more important for lower quantiles, particularly at age 40 years. Only rapid growth from ages 1 to 7 years was an important predictor of adult BMI at both age 20 and age 40, irrespective of statistical model. However, the persistence of effects of maternal and infant factors on adult BMI, even after rapid childhood growth is accounted for, suggests a greater need to investigate these early-life influences and whether their impact differs for smaller and larger women.

birth weight; body mass index; body size; growth; obesity; overweight

Abbreviation: BMI, body mass index.

Editor's note: *An invited commentary on this article appears on page 14, and the authors' response appears on page 17.*

Examining the role early-life factors may play in shaping adult body size is crucial to understanding human growth and preventing obesity. The positive correlation between birth weight and adult body size has motivated a search for the fetal origins of obesity (see reviews by Oken and Gillman (1) and Monteiro and Victora (2)). The findings of several large, well-conducted studies have supported a role for early-life factors in influencing adult body size (3–8). These studies illustrate the need to jointly examine maternal, infant, and childhood factors in order to estimate whether such factors operate independently or through other factors. For example, some studies with information on both birth weight and maternal body mass index (BMI; weight (kg)/height (m)^2) have suggested that maternal BMI may be responsible for some of the previous correlations between birth weight and adult body size (3, 9).

Just as it is important to deconstruct birth weight and understand what it represents, it is also important to collect multiple measures of infant and childhood growth, because

Correspondence to Dr. Mary Beth Terry, Department of Epidemiology, Mailman School of Public Health, Columbia University, 722 West 168th Street, Room 724 A, New York, NY 10032 (e-mail: mt146@columbia.edu).

many maternal and infant factors probably influence adult body size through their impact on childhood growth. The results of two studies have supported a long-term effect of rapid growth during the first year of life (7, 8). If rapid infant growth predicts larger adult body size even after childhood growth patterns have been considered, it may be necessary to target multiple critical time points in long-term obesity prevention efforts.

Investigators in previous studies have examined the impact these early-life factors may have on adult body size primarily by considering their effect on mean adult BMI (linear regression) and/or the risk of being overweight (BMI $\geq$ 25) (logistic regression). We compared these standard methods with another method of estimation using quantile regression (10), which allows the effect of each factor to vary by the quantile of the response variable. The effects of maternal factors and early growth on persons who are underweight or overweight in adulthood may differ from those in the average cohort. Quantifying these differences, where they may exist, is crucial in designing health promotion interventions appropriate for different ranges of adult BMI and not just the average. We followed a birth cohort of women born in New York City from 1959 to 1965 in order to jointly examine the effect maternal factors (maternal BMI and pregnancy weight gain), birth measures (birth weight and placental weight), and infant and early childhood growth have on adult body size. We further examined whether the impact of these factors differs between smaller and larger women.

MATERIALS AND METHODS

Study participants

All women born at Columbia-Presbyterian Medical Center (New York, New York) from 1959 to 1965 who were included in the National Collaborative Perinatal Project until age 7 years were eligible for participation; there were 809 women eligible. Of the 340 participants (42 percent of the original cohort) we were able to trace, 77 percent participated in the adult follow-up (2001–2006); 38 percent were White, 40 percent were African-American, and 22 percent were Latina. The study was approved by the Internal Review Board at Columbia-Presbyterian Medical Center. Further details on the National Collaborative Perinatal Project are available elsewhere (11).

Growth data

Mothers were enrolled in the National Collaborative Perinatal Project during their second or third trimester of pregnancy. Prospective data on several growth measures, including birth weight, birth length, placental weight, and weight and height at ages 4 months, 1 year, 4 years, and 7 years, were obtained by trained clinical researchers using a standard protocol (11). Because the subjects did not all attend clinical examinations at exactly these time points, and to reduce any potential bias arising from the shifted measurement times, we interpolated these measurements at the target times using individual cubic interpolation splines. No interpolation was needed for birth measurements. Maternal weight gain and maternal prepregnancy BMI were based on weight and height measured prior to birth and reported weight prior to pregnancy, respectively.

Adult data

We sent a questionnaire to all women who were successfully traced to obtain information on adult body size (height and weight at ages 20 years and 40 years) and other information about adult health and reproductive events.

Statistical analyses

Most studies of adult body size apply either linear regression methods with BMI entered as a continuous dependent variable or logistic regression methods with BMI entered as a dichotomized dependent variable (usually defined as overweight (BMI $\geq$ 25) vs. not overweight). These methods assume that the relation between independent variables and the dependent variable is the same irrespective of the scale of adult BMI. We used quantile regression (10) to estimate the effect of maternal, birth, and postnatal growth at various quantiles of the adult BMI distribution. Quantile regression aims at fully examining the effect of X on the entire distribution of Y, not just the mean value of Y. We selected the quantiles by internal percentile rank, rather than using absolute cutoff values.

We characterized an individual growth trajectory according to four parameters: birth measurement and percentile rank changes over three consecutive periods, from birth to age 4 months, from age 4 months to age 1 year, and from age 1 year to age 7 years. The changes in percentile rank provided us with a convenient and intuitive way to assess the growth rate while avoiding additional adjustment for age-dependent measurement scales. We defined three main patterns of growth: rapid, stable, and slow. Rapid growth defined participants whose percentile rank increased across two major reference percentiles of growth from birth to age 7 years. Reference percentiles were defined by standard Centers for Disease Control and Prevention growth charts as the 5th, 10th, 25th, 50th, 75th, and 95th percentiles. Stable growth defined participants whose percentile rank stayed within two major percentiles from birth to age 7 years. Slow growth defined participants whose percentile rank decreased across two major percentiles from birth to age 7 years.

We modeled the relation beween maternal factors (BMI and pregnancy weight gain), birth weight, and growth during the three time periods (birth–4 months, 4 months–1 year, and 1–7 years) using linear quantile regression models and standard methods (ordinary linear regression and logistic regression) for comparison. We also examined whether the following variables added to the overall goodness of fit of the base model (12, 13): length of gestation, preeclampsia, placental weight, race, socioeconomic status at birth, and childhood socioeconomic status measured at age 7 years. We examined the overall goodness of fit by calculating the relative deviance, which is the counterpart of R^2 in ordinary linear mean regression (14). Finally, to study the long-term

TABLE 1. Characteristics of women in the New York Women's Birth Cohort (women born in 1959–1965) who participated in adult follow-up, 2001–2006

	Women in adult cohort (n = 261)				All subjects eligible for adult follow-up (n = 809)	
	Mean	SD*	%	Median	Mean	SD
Birth weight (g)	3,138.2	490.0		3,147.0	3,126.9	488.4
Placental weight (g)	452.4	92.7		450.0	447.0	92.0
Length of gestation (weeks)	39.5	2.6		40.0	39.3	3.0
Maternal prepregnancy BMI*,†	22.5	3.7		21.9	22.6	4.1
Maternal weight gain (pounds‡) during pregnancy	23.2	11.0		22.0	23.1	10.7
Weight (g) at age 4 months	6,103.2	782.6		6,095.0	6,138.0	776.8
Weight (kg) at age 1 year	9.6	1.1		9.6	9.69	1.26
Weight (kg) at age 4 years	17.0	2.8		16.3	17.2	3.1
Weight (kg) at age 7 years	23.9	4.9		22.8	24.3	5.3
Weight (kg) at age 20 years	58.7	12.2		55.8	NA*	
Height (m) at age 20 years	1.64	0.07		1.6	NA	
BMI at age 20 years	22.0	4.3		21.1	NA	
BMI <25 (normal weight)			87			
BMI ≥25 (overweight)			13			
BMI at age 40 years	27.2	6.9		25.8	NA	
BMI <25 (normal weight)			46			
BMI ≥25 (overweight)			54			

* SD, standard deviation; BMI, body mass index; NA, not applicable.
† Weight (kg)/height (m)^2.
‡ 1 pound = 0.45 kg.

effect of the covariates, we applied the same models to BMI at age 40 years.

RESULTS

Table 1 shows descriptive statistics for the cohort. Women who participated in the adult follow-up did not differ from the overall cohort of eligible participants with regard to any of the infant and childhood growth measures. Table 2 shows the associations according to three percentiles (10th, 50th, and 90th) for three models examining the maternal variables (model 1), the maternal variables plus birth weight (model 2), and the maternal variables, birth weight, and postnatal growth variables (model 3). The parameter estimates differ across percentiles, suggesting that standard regression methods would not fully describe associations between these factors and adult body size. The parameter estimates are fairly stable across the three models for maternal BMI and maternal weight gain, suggesting that there is little mediation of these factors by birth weight and infant and childhood growth measures. Birth weight estimates, however, change significantly with the addition of the postnatal growth variables. Specifically, after the addition of the postnatal growth variables, the effect of birth weight is positive for the lower quantiles (≤50th percentile).

Table 3 presents results from the comparison of three statistical regression methods (quantile regression, ordinary linear regression, and logistic regression dichotomizing BMI into overweight (BMI ≥ 25) versus not overweight (BMI < 25)). Both linear and logistic regression models supported positive associations for maternal weight gain, birth weight, and rapid postnatal growth. The parameter estimates presented in the table reflect a one-unit increase in each covariate (weight gain in pounds, birth weight in kg, and all child growth measures expressed as percentile change for the time period). The last section of the table translates the logistic regression estimates into interpretable units, by variable. For example, maternal weight gain and postnatal growth were associated with being overweight (BMI ≥ 25) at age 20 years (per 10 pounds (4.5 kg) of maternal weight gain, odds ratio = 1.65, 95 percent confidence interval: 1.11, 2.44; per 10 percent change in rate of growth from ages 1 to 7 years, odds ratio = 1.73, 95 percent confidence interval: 1.36, 2.19). Estimates for all of the covariates differed by quantile of BMI, which cannot be observed using linear and logistic regression methods. For example, the impact of maternal BMI varied by quantile and was not significant in the logistic model. Maternal weight gain had a strong association with BMI at age 20 years for the upper quantiles (≥75th percentile), but the association was underestimated using ordinary linear regression. Birth weight was not associated with BMI at age 20 years among larger women (90th percentile). Growth during the first 4 months of life was associated with BMI at age 20 years for

TABLE 2. Association between early-life growth and maternal factors and body mass index at age 20 years, New York Women's Birth Cohort adult follow-up, 2001–2006

Covariate	Model 1†						Model 2‡						Model 3§					
	10th percentile		50th percentile		90th percentile		10th percentile		50th percentile		90th percentile		10th percentile		50th percentile		90th percentile	
	β	SE¶	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE
Maternal body mass index#	0.15	0.09	0.21*	0.09	0.49*	0.20	0.16	0.11	0.21*	0.11	0.69*	0.28	0.18*	0.07	0.20	0.10	0.56**	0.21
Maternal weight gain (pounds††) during pregnancy	−0.01	0.02	0.03	0.04	0.22**	0.09	−0.01	0.02	0.03	0.04	0.25**	0.08	−0.001	0.03	0.04	0.03	0.24**	0.07
Birth weight (kg)							0.19	0.48	0.08	0.85	−2.71	2.10	1.54**	0.47	1.85*	0.73	0.62	2.01
Postnatal growth rate (percentile change)																		
Birth–age 4 months													0.03*	0.01	0.04**	0.01	0.05	0.03
Ages 4 months–1 year													0.03**	0.01	0.03**	0.01	0.06*	0.03
Ages 1–7 years													0.04**	0.01	0.06**	0.02	0.10**	0.03

* $p \leq 0.05$; ** $p \leq 0.01$.
† Model 1: maternal variables (body mass index and weight gain during pregnancy).
‡ Model 2: the maternal variables plus birth weight.
§ Model 3: the maternal variables plus birth weight and postnatal growth variables (birth–4 months, 4 months–1 year, and 1–7 years).
¶ SE, standard error.
# Weight (kg)/height (m)^2.
†† 1 pound = 0.45 kg.

all percentiles but the 90th. Rapid growth from ages 1 to 7 years was associated with adult BMI for all percentiles.

Table 3 also shows the overall goodness of fit for the quantile regression model. The difference between the model-based empirical distribution and its nominal values ranged from 0.00 to 0.02, suggesting that the model fitted the data very well. After adjustment for the factors listed in table 3, race, socioeconomic score at birth and at age 7 years, length of gestation, preeclampsia, placental weight, and maternal smoking status did not statistically improve the prediction of BMI at age 20 years. Table 3 also ranks the covariates in order of importance in overall model fitness, on the basis of deviance statistics (with a lower ranking indicating more importance in predicting BMI). Although all of the variables were important predictors, the relative ranking suggested that rapid growth from ages 1 to 7 years, maternal BMI, and rapid growth during the first 4 months of life had the most predictive power for the lower quantiles (≤50th percentile), whereas rapid growth from ages 1 to 7 years, maternal BMI, and maternal weight gain had the most predictive power for the upper quantiles of BMI at age 20 years (≥75th percentile).

Figures 1 and 2 illustrate the estimated conditional distributions of adult BMI given combinations of pre- and postnatal factors. The *x*-axis of each graph shows the quantile level, and the *y*-axis shows the corresponding adult BMI. In each panel, we altered one risk factor while maintaining the others at constant levels, which enabled us to study the impact of that factor on the entire distribution of adult BMIs. BMIs of 25 and 30 represent the cutoff values used to define overweight and obesity, respectively.

Figure 1 shows the association between maternal weight gain and BMI at age 20 years, conditional on stable postnatal growth, median birth weight (3.2 kg), and median maternal BMI (21.9), obtained using the parameter estimates from table 3. Women born to mothers who gained more weight during pregnancy (90th percentile (panel C)) were more likely to be overweight (BMI ≥ 25) at age 20 years than women whose mothers gained less weight during pregnancy (10th (panel A) and 50th (panel B) percentiles).

Figure 2 shows the combined effects of birth weight and postnatal growth on adult BMI. Conditional on low birth weight, participants who experienced rapid growth from ages 1 to 7 years (panel C) were more likely to be overweight at age 20 years than those who experienced rapid growth from birth to age 4 months (panel B) or stable postnatal growth (panel A). Conditional on high birth weight, participants who experienced stable postnatal growth (panel D) were more likely to be overweight at age 20 years than those who experienced slower growth from birth to age 4 months (panel E). Panel F shows that large babies who experienced slower growth from ages 1 to 7 years were unlikely to be overweight at age 20 years. Thus, low birth weight babies who experienced rapid growth from ages 1 to 7 years were the most likely to be overweight at age 20 years.

Table 4 shows the relations with BMI at age 40 years. Rapid growth from ages 1 to 7 years was the only variable that was important for all quantiles of BMI at age 40 years. Maternal BMI was important for all percentiles but the 90th. Maternal weight gain and birth weight were no longer

TABLE 3. Associations of maternal factors, birth weight, and early-life growth with body mass index at age 20 years, New York Women's Birth Cohort adult follow-up, 2001–2006

	Quantile†															Model						
	10th percentile			25th percentile			50th percentile			75th percentile			90th percentile			Linear model‡		Logistic model§				
	β	SE¶	Rank#	β	SE	Rank#	β	SE	Rank#	β	SE	Rank#	β	SE	Rank#	β	SE	β	SE	OR¶	95% CI¶	Increment of change for OR
Maternal body mass index††	0.18*	0.07	1	0.14*	0.07	1	0.19	0.11	2	0.36**	0.10	2	0.56**	0.20	3	0.30**	0.08	0.12	0.07	1.13	0.98, 1.29	1 unit
Maternal weight gain (pounds‡‡) during pregnancy	−0.002	0.03	6	0.02	0.03	6	0.04	0.03	5	0.13**	0.04	3	0.24**	0.06	2	0.10**	0.03	0.05*	0.02	1.65	1.11, 2.44	10 pounds (4.5 kg)
Birth weight (kg)	1.54**	0.48	4	1.71**	0.62	4	1.85*	0.78	6	1.82*	0.90	6	0.62	1.89	6	1.47*	0.73	2.65**	0.78	3.76	1.75, 8.08	500 g
Postnatal growth rate (percentile change)																						
Birth–age 4 months	0.03**	0.01	3	0.04**	0.01	3	0.04**	0.01	3	0.05*	0.02	4	0.05	0.03	4	0.05**	0.01	0.05**	0.01	1.65	1.30, 2.09	10% change
Ages 4 months–1 year	0.03**	0.01	5	0.02	0.01	5	0.03**	0.01	4	0.05**	0.01	5	0.06*	0.03	5	0.05**	0.01	0.04**	0.01	1.48	1.13, 1.93	10% change
Ages 1–7 years	0.03**	0.01	2	0.05**	0.01	2	0.06**	0.01	1	0.07**	0.02	1	0.10**	0.03	1	0.07**	0.01	0.05**	0.01	1.73	1.36, 2.19	10% change
Goodness of fit ($\hat{\tau} - \tau$)		0.00			0.01			0.00			0.02			0.01								

* $p \leq 0.05$; **$p \leq 0.01$.
† Parameter estimates and standard errors based on quantile regression methods, by quantile.
‡ Parameter estimates and standard errors from ordinary least-squares regression.
§ Parameter estimates and standard errors from a logistic model comparing body mass index ≥ 25 with body mass index < 25.
# Ranking of relative predictive importance based on relative deviance.
¶ SE, standard error; OR, odds ratio; CI, confidence interval.
†† Weight (kg)/height $(m)^2$.
‡‡ 1 pound = 0.45 kg.

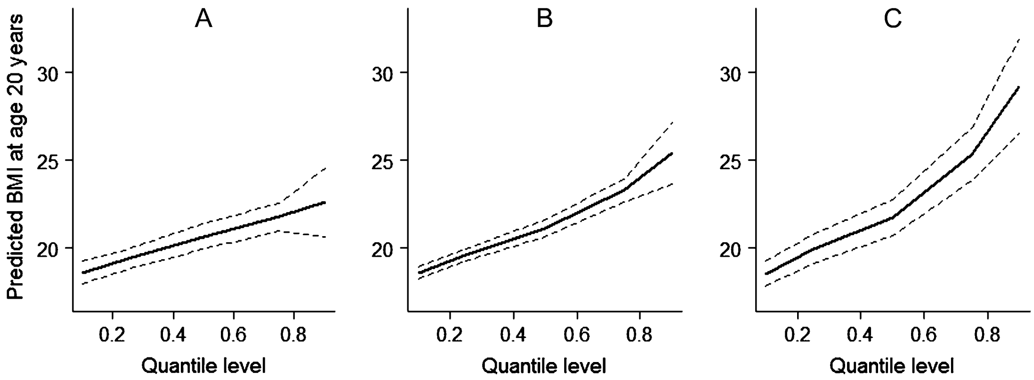

FIGURE 1. Association between maternal weight gain during pregnancy and offspring's body mass index (BMI; weight (kg)/height (m)^2) at age 20 years, conditional on stable postnatal growth, New York Women's Birth Cohort (women born in 1959–1965). The *x*-axis represents the quantile level (e.g., 0.2 = 20th percentile) of offspring BMI, and the *y*-axis represents the corresponding predicted BMI at age 20 years based on the quantile-specific parameter estimates and the following covariate settings: stable postnatal growth (no change in percentile rank), median birth weight (3.2 kg), and median maternal prepregnancy BMI (21.9). Maternal weight gain varies as follows: panel A—10th percentile of maternal weight gain (11 pounds (5 kg)); panel B—50th percentile of maternal weight gain (22 pounds (10 kg)); panel C—90th percentile of maternal weight gain (37.4 pounds (17 kg)). The dotted lines represent pointwise 95 percent confidence intervals.

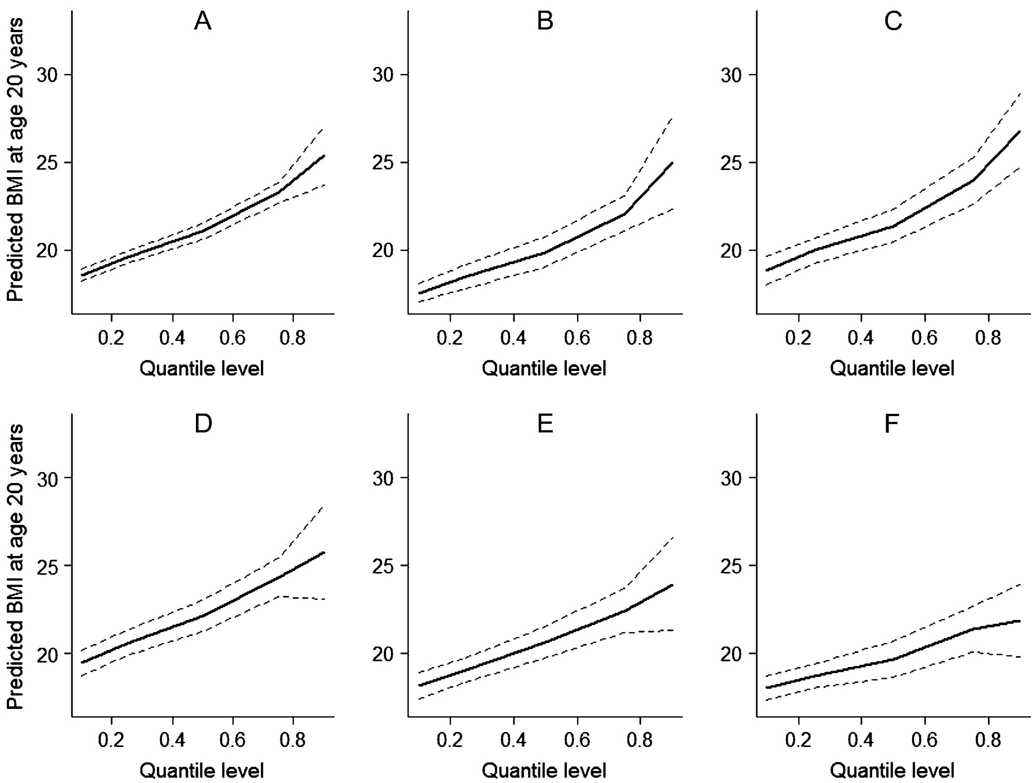

FIGURE 2. Association between postnatal growth velocity and body mass index (BMI; weight (kg)/height (m)^2) at age 20 years, conditional on birth weight, New York Women's Birth Cohort (women born in 1959–1965). The *x*-axis represents the quantile level (e.g., 0.2 = 20th percentile) of BMI, and the *y*-axis represents the corresponding predicted BMI at age 20 years based on the quantile-specific parameter estimates and the following covariate settings. Panels A–C show results from models conditional on low birth weight (10th percentile = 2.5 kg) and median maternal prepregnancy BMI (21.8) and median maternal weight gain (22 pounds (10 kg)) during pregnancy and three types of postnatal growth: stable postnatal growth (panel A), rapid postnatal growth from birth to age 4 months (panel B), and rapid postnatal growth from ages 1 to 7 years (panel C). Panels D–F show results from models conditional on high birth weight (90th percentile = 3.7 kg) and median maternal BMI (21.8) and median maternal weight gain (22 pounds (10 kg)) and three types of postnatal growth: stable postnatal growth (panel D), slow postnatal growth from birth to age 4 months (panel E), and slow postnatal growth from ages 1 to 7 years (panel F). The dotted lines represent pointwise 95 percent confidence intervals.

TABLE 4. Associations of maternal factors, birth weight, and early-life growth with body mass index at age 40 years, New York Women's Birth Cohort adult follow-up, 2001–2006

	Quantile†															Model						
	10th percentile			25th percentile			50th percentile			75th percentile			90th percentile			Linear model‡		Logistic model§				
	β	SE¶	Rank#	β	SE	Rank#	β	SE	Rank#	β	SE	Rank#	β	SE	Rank#	β	SE	β	SE	OR¶	95% CI¶	Increment of change for OR
Maternal body mass index††	0.31**	0.11	1	0.36**	0.11	1	0.26	0.15	1	0.37*	0.17	2	0.29	0.31	2	0.38**	0.13	0.12*	0.05	1.13	1.03, 1.24	1 unit
Maternal weight gain (pounds‡‡) during pregnancy	0.04	0.05	3	0.02	0.04	4	0.08	0.05	4	0.14	0.08	3	0.21	0.12	3	0.07	0.04	0.03	0.02	1.30	0.96, 1.77	10 pounds (4.5 kg)
Birth weight (kg)	1.29	1.15	6	0.48	1.15	6	1.72	1.43	5	2.24	1.70	5	4.96	2.62	4	2.50*	1.19	0.38	0.41	1.21	0.81, 1.80	500 g
Postnatal growth rate (percentile change)																						
Birth–age 4 months	0.05*	0.02	4	0.02	0.02	3	0.04	0.02	3	0.07*	0.03	3	0.00	0.04	6	0.04*	0.02	0.01*	0.01	1.16	1.01, 1.33	10% change
Ages 4 months–1 year	0.04*	0.02	5	0.01	0.02	5	0.01	0.03	6	0.03	0.02	6	0.04	0.04	5	0.03	0.02	0.01	0.01	1.10	0.95, 1.27	10% change
Ages 1–7 years	0.05*	0.02	2	0.05**	0.02	2	0.09**	0.03	2	0.12**	0.02	1	0.18**	0.05	1	0.10**	0.02	0.03**	0.01	1.28	1.12, 1.46	10% change
Goodness of fit ($\hat{\tau} - \tau$)		0.03			0.02			−0.03			−0.02			0.00								

* $p \leq 0.05$; ** $p \leq 0.01$.
† Parameter estimates and standard errors based on quantile regression methods, by quantile.
‡ Parameter estimates and standard errors from ordinary least-squares regression.
§ Parameter estimates and standard errors from a logistic model comparing body mass index ≥ 25 with body mass index < 25.
# Ranking of relative predictive importance based on relative deviance.
¶ SE, standard error; OR, odds ratio; CI, confidence interval.
†† Weight (kg)/height (m)^2.
‡‡ 1 pound = 0.45 kg.

significant in the prediction of BMI at age 40 years at any quantile level. In addition, the variability of the parameter estimates increased, particularly for birth weight, but the overall fit of the model remained good. The linear and logistic models also supported an association between maternal BMI and growth from ages 1 to 7 years and BMI at age 40 years. In addition, the linear model supported an association between birth weight and rapid growth from ages 1 to 4 months. The logistic model did not indicate any relation with birth weight but supported an association between rapid growth during the first 4 months of life and BMI at age 40 years.

DISCUSSION

We found that maternal BMI, maternal weight gain, birth weight, and rapid childhood growth had long-lasting effects on adult body size in women but that the impact of these factors differed between larger and smaller adult women. Rapid growth from ages 1 to 7 years and maternal prepregnancy BMI were the most important predictors for all percentiles of age-20 BMI except the 90th percentile, where maternal weight gain was more important than maternal BMI. Rapid growth from ages 1 to 7 years and maternal prepregnancy BMI were the most important factors predicting BMI at age 40 years. Stettler et al. have argued that rapid growth during the first few months, or even weeks, of life may be associated with greater childhood (15) and adult (8) obesity. We also observed a strong association between rapid growth from birth to age 4 months and BMI at age 20 years for all percentiles below the 90th. Interestingly, rapid growth during the first 4 months of life was also associated with BMI at age 40 years in both linear and logistic models and was important for the 10th and 75th percentiles of BMI at age 40 years. This suggests that while rapid childhood growth from ages 1 to 7 years is most important in predicting adult BMI, early infant growth is also independently predictive of adult BMI.

The strong association between maternal prepregnancy BMI and adult body size may reflect some combination, as Whitaker and Dietz (16) and others have argued, of transmitted genes as well as environmental influences (17, 18). Even after accounting for maternal prepregnancy BMI, we found a strong association between maternal weight gain and body size at age 20 years among larger women ($\geq$75th percentile). This observation suggests that pregnancy-specific weight gain may have a persistent long-term impact on the offspring's adult BMI. Thus, our study supports the work of Dietz (19), which suggested that there are critical periods influencing adult body size, including the intrauterine period, early infancy, and early childhood. While we did not have data on body size during adolescence, our observed and predicted values of adult BMI were very close, suggesting that the unexplained portion of the model was small.

After we accounted for both postnatal growth rates and maternal variables, birth weight was still associated with body size at age 20 years among all but the largest women ($\leq$75th percentile). However, we did not find that this association held for larger women—an observation that would be lost without the quantile-specific estimates. Our data help to illustrate why studies examining just birth weight and adult body size are incomplete, because the effect of birth weight may be different among smaller and larger women.

In this study, we wanted to examine whether pre- and postnatal factors were associated with adult BMI and, further, whether these factors were similar across quantiles of BMI. We did not assume that the influences of these factors were the same for larger and smaller women. Just as ordinary mean regression estimates the influence of risk factors on the "population average," quantile regression allows for complete examination of their influences on the entire distribution of adult BMIs. If our estimates were the same for all quantiles of adult BMI, then ordinary linear regression would be appropriate. Logistic regression is flexible and easy to interpret, but it requires a subjective choice of the threshold. For example, the cutpoint used to define overweight on the basis of BMI has changed over time (20). In contrast, in quantile regression, the overweight and underweight cutpoints are determined by internal percentile ranks.

We considered other methods, such as nonlinear regression, which models the mean of the response variable (Y) as a nonlinear function of the covariates (X). In contrast, quantile regression aims at fully examining the effect of X on the entire distribution of Y, not just on the mean value of Y. Differences across quantile levels of Y do not imply that the mean of Y is nonlinear. The effect on the quantile level could be either linear or nonlinear. This method of estimation has already been applied in a number of health-related investigations (21–27). Thus, by modeling our data with quantile regression, as well as comparing our estimates with the results of more standard approaches, we were able to examine whether pre- and postnatal factors differed for smaller and larger women. Differences by quantiles suggest that factors may differentially affect the adipose/lean tissue proportion and may suggest underlying pathways linking these observations.

Our findings are unlikely to have been influenced by selection bias, because subjects who were lost to follow-up did not differ from subjects who were not lost according to any of the growth or maternal factors examined. Data on all infant and childhood measures were collected prospectively using a uniform measurement protocol. Nondifferential measurement error in adult BMI would lead to attenuated associations and therefore cannot explain the findings that we report here. However, if adult women differentially reported their weight such that overweight women were more likely to underreport than average-weight women, we would expect to see even stronger correlations given the positive correlation between childhood weight and adult weight. We were able to assess confounding by a number of factors, including socioeconomic status at birth and age 7 years. We also assessed other important growth measures, including placental weight, birth length, and height changes during infancy and early childhood. These other measures did not improve the overall fit of the model, so we did not include them in our final model. In addition, other maternal obstetrical conditions such as preeclampsia and hypertension did not improve the fit of the overall model. Too few mothers had gestational diabetes for assessment of the impact of this condition on the growth parameters.

Our study suggests that adult body size is influenced by high maternal BMI and rapid postnatal growth. Even after these factors have been accounted for, birth weight is still an important predictor of adult BMI among smaller women and maternal weight gain is an important predictor among larger women. There is no reason to expect that factors should operate the same way across the continuum of adult BMI. Thus, is it possible, and plausible, that these relations may operate differently for larger and smaller women. Understanding the biologic relations underpinning these observations is paramount, since childhood obesity prevalence (28), birth weight (29), and maternal weight gain during pregnancy (30) are all increasing. For example, the median weight gain in the United States in 2003 was 30.5 pounds (13.9 kg) (30), 8.5 pounds (3.9 kg) more than the median in our cohort; our models suggest that this change alone would lead to an increase of more than two points in BMI at age 20 years among larger women, or a 50 percent overall increase in the risk of being overweight. Because the average age at pregnancy is also increasing, and BMI increases with age in most populations, maternal prepregnancy BMI is probably higher as well. If our findings are replicated, these trends all point to dramatic long-term consequences for the prevalence of overweight in adulthood.

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