# Pre-, Perinatal, and Parental Predictors of Body Mass Index Trajectory Milestones

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**Objective** To assess associations of pre-, perinatal, and parental factors with age and magnitude at body mass index (BMI) peak and rebound.

**Study design** Among 1681 children with BMI data from birth to mid-childhood in Project Viva, we fitted individual BMI trajectories using mixed-effect models with natural cubic spline functions and estimated age and magnitude at peak in infancy and rebound in early childhood. We used stepwise multivariable regression to identify predictors of peak and rebound in the 1354 (63.6%) children with estimable trajectory milestones.

**Results** The mean (SD) of age at BMI peak was 8.4 (2.7) months and at rebound was 59.8 (19.6) months, and the mean (SD) of magnitude at peak was 18.0 (1.4) kg/m$^2$ and at rebound was 15.9 (1.2) kg/m$^2$. Girls had a later age at peak, earlier age at rebound, and lower magnitudes at peak and rebound than boys. Maternal isolated hyperglycemia (vs normoglycemia: $\beta$ 0.7 months [95% CI 0.2-1.2]) and pre-eclampsia (vs normal blood pressure: 1.6 months [0.8-2.4]) were associated with a later peak, and impaired glucose tolerance (vs normoglycemia: –0.5 kg/m$^2$ [–0.9, –0.1]) was associated with a lower magnitude at peak. Greater maternal first-trimester weight gain, smoking during pregnancy, no breastfeeding, parental obesity, and no university education were associated with greater BMI at rebound.

**Conclusions** We have identified modifiable prenatal and parental predictors of BMI peak in infancy and rebound in childhood. Early-life interventions that address these factors may be effective in changing BMI peak and rebound and potentially preventing later obesity. *(J Pediatr 2018;■■:■■-■■).*

Body mass index (BMI) typically increases to a maximum during the first year of life (BMI peak), followed by a decline to a nadir (BMI rebound) between 4 and 6 years of age.[1] A later age and greater magnitude at peak predict adiposity and cardiometabolic outcomes later in childhood.[2,3] Early age at BMI rebound (<4 years) also has been linked to greater adiposity,[4] risk of obesity,[5] and metabolic dysfunction[6] in adolescence. An understanding of the determinants of BMI peak and rebound is therefore important in developing strategies to prevent obesity and its associated cardiometabolic disease risk.

Genetic determinants of adult BMI also have observable effects on age and magnitude at BMI peak and rebound.[7] Studies by Roy et al and Wen et al have characterized ethnic differences in BMI peak and rebound, respectively.[1,8] The evidence surrounding the role of infant nutrition, such as breastfeeding, on BMI peak and rebound remains inconclusive.[2,9-12] Few reports have described prenatal determinants of BMI peak and rebound, other than maternal obesity and gestational weight gain.[2,13-15] Although earlier studies have reported associations of gestational exposures such as glucose intolerance,[16] hypertensive disorders,[17] and smoking[18] with childhood BMI, these factors have yet to be related to characteristics of BMI peak and rebound. Furthermore, evidence remains scant regarding the relationship of paternal factors (eg, obesity and socioeconomic status) with BMI peak and rebound.

We used data from Project Viva, a longitudinal Boston-area prebirth cohort, to assess associations of maternal, paternal, and child factors with characteristics of BMI peak and rebound. We hypothesized that known risk factors of childhood adiposity, such as obesity and socioeconomic status of both parents and maternal smoking, greater gestational weight gain, glucose intolerance, and hypertensive disorders,[13,14,16-18] would predict age at and magnitude of BMI peak and rebound.

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| BMI | Body mass index |
| GDM | Gestational diabetes mellitus |
| IGT | Impaired glucose intolerance |

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## Methods

Children were participants in Project Viva, an ongoing prospective cohort study of pre- and perinatal influences on maternal, fetal, and child health. We recruited eligible pregnant women at clinical visits during the first trimester of pregnancy between 1999 and 2002 from 8 obstetric offices of Atrius Harvard Vanguard Medical Associations, a multisite group practice in Eastern Massachusetts, as detailed elsewhere.[19] Of 2128 live singleton births, we modeled BMI trajectories in 1681 (78.9%) children who had ≥3 BMI measurements from birth to mid-childhood (median 92.5; range 78.8-131.2 months) (**Figure 1**; available at www.jpeds.com), for a total of 20 598 BMI measurements (**Table I**; available at www.jpeds.com).

Mothers provided written informed consent at enrollment and each postnatal follow-up visit at infancy, early, and mid-childhood. The institutional review board of Harvard Pilgrim Health Care approved the project in line with ethical standards established by Declaration of Helsinki.

### Parental Obesity

Mothers reported their prepregnancy weight, height, and father's weight and height via questionnaires and interviews at recruitment. We calculated prepregnancy and paternal BMI (in kg/m$^2$) as self-reported prepregnancy or paternal weight divided by height squared respectively, and categorized obesity as follows: both nonobese (prepregnancy and paternal BMI <30 kg/m$^2$), only mother obese (prepregnancy BMI ≥30 kg/m$^2$), only father obese (paternal BMI ≥30 kg/m$^2$), or both obese (prepregnancy and paternal BMI ≥30 kg/m$^2$).

### Parental Socioeconomic Status

Mothers reported their and fathers' highest education via questionnaires and interviews at recruitment. We categorized parental educational level as neither university-educated or mother, father, or both university-educated. We also calculated median annual household income for census tract of residence at delivery using data from the 2000 US Census.[20]

### Other Maternal Factors

Mothers reported their smoking history via questionnaires at recruitment. As detailed previously,[21] we used measured weights recorded in the outpatient medical records and self-reported prepregnancy weight to calculate trimester-specific gestational weight gain. We obtained results of a 2-stage clinical glycemic screening and used them to categorize women as having normoglycemia, isolated hyperglycemia, impaired glucose tolerance (IGT), or gestational diabetes (GDM), based on criteria previously detailed.[16] We also extracted data on parity and hypertensive disorders of pregnancy (normal blood pressure, gestational hypertension, chronic hypertension, or preeclampsia) from hospital medical records.

### Child Factors

We extracted data on infant sex and birth weight from hospital medical records. We calculated length of gestation in days by subtracting the date of the last menstrual period from the date of delivery. If gestational age according to the second-trimester ultrasound scan differed from that according to the last menstrual period by >10 days, we used the ultrasound result to determine gestational duration. We calculated birth weight-for-gestational age and sex z scores from a US national reference.[22] The mother reported her child's race/ethnicity, which we categorized as white, black, Hispanic, Asian, or other. We obtained information on initiation of breastfeeding at postdelivery interviews, as detailed previously.[23]

During research examinations at birth, in infancy (median 6.3 months; range 4.9-10.6 months), early childhood (37.9; 33.6-72.5 months), and mid-childhood (92.5; 78.8-131.2 months),[19] trained research assistants measured weight and length/height using standardized protocols.[16,24,25] We also obtained additional data on weight and length/height from medical records, where pediatric clinics recorded length/height and weight data at each well-child visit during infancy and childhood. As described previously, clinicians used the paper-and-pencil technique for measuring recumbent length for infants 0-2 years at pediatric clinics.[26] We applied a correction algorithm to account for the systematic overestimation of clinical lengths resulting from this technique.[26] Using both research and clinical measures, we calculated BMI as weight in kilograms divided by length or height in meters squared.

### Statistical Analyses

To estimate BMI peak and rebound, we used statistical models, rather than direct observations and visual inspection of individual BMI-for-age curves,[27] which is prone to large interobserver variation.[28] Furthermore, not every child had multiple measures of weight and stature at enough time points to allow us to directly observe the peak and rebound characteristics; applying the models allowed us to estimate these characteristics for a larger number of children in the cohort. We fitted individual BMI curves using mixed-effects models with natural cubic spline functions for age to capture the nonlinear trend in BMI. Random effects were included in the model to account for repeated measures in the same child and to capture the nonlinear trend in BMI. We applied constraints to increase stability of the curve[29] by fixing the spline to be linear prior to 0.1 months and after 131.1 months. The fixed effects component of the model was as follows:

$$BMI = \beta_{00} + \beta_{10}(\text{age}) + \sum_{j=1}^{m} \beta_j \left\{ (\text{age} - k_j)^3_+ - \lambda_j (\text{age} - k_{\min})^3_+ - (1-\lambda_j)(\text{age} - k_{\max})^3_+ \right\} + e_{ij}$$

where *kmin* and *kmax* = boundary knots, *kj* = interior knot point *j* between boundary knots; *m* = number of interior knots between boundary knots; *j* = 1, 2, . . ., m; *e* = residual and $(\text{age}-k_j)^3_+$ is defined as age–k if age ≥ $k_j$. The random effects component of the model contained random effects for the intercept, linear age slopes, and spline functions.

We considered 2 approaches to select knot locations: at equally spaced percentiles[30] between birth and 131.2 months or at the median, minimum, and maximum ages of each of 3 developmental periods: infancy and early and mid-childhood.



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