Maternal pre-pregnancy body mass index, child temperament, and childhood obesity risk

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Abstract

Background

Maternal obesity prior to and during pregnancy is related to increased risk of obesity in the child. This risk may be in part mediated by altered child temperament, which can affect mother-child interactions including feeding and soothing behaviors that affect obesity risk. Our objective was to examine the association between maternal pre-pregnancy BMI and child zBMI, and determine if child temperament, specifically positive affectivity/surgency, mediates this association.

Methods

Using conditional process modeling, we analyzed prospectively collected data from 408 mother-child dyads enrolled in the Alberta Pregnancy Outcomes and Nutrition (APrON) study. Child temperament was assessed by the Child Behaviour Questionnaire (CBQ) Very Short Form at 3 years of age and zBMI was calculated from in-clinic height and weight measurements at 4 years of age.

Results

The indirect effect of pre-pregnancy BMI on child zBMI through Surgency scores as a mediator was significant after controlling for maternal gestational weight gain, socioeconomic status, maternal anxiety and depression, and child cognitive and emotional support (β = 0.003, 95% CI [0.0001, 0.008]). Overall, maternal pre-pregnancy BMI and child zBMI were directly associated and there was an indirect association through child temperament, whereby increased Surgency was associated with higher zBMI scores.

Conclusions

Child zBMI score is associated with maternal pre-pregnancy BMI, and this relationship is mediated by the temperament of the child, specifically Surgency.

Introduction

Worldwide obesity has tripled since 1975, with 39 million children under the age of 5 classified as overweight or obese in 2020. Obesity is preventable, and childhood obesity increases the risk of obesity in adulthood, which greatly increases the risk of comorbidities such as cardiovascular disease. The rapid increase in obesity rates suggest that genetic changes are not the likely cause of the obesity epidemic, but rather it is the result of environmental factors such as increased availability of energy-dense, nutrient-poor foods and drinks. Maternal obesity increases the incidence of gestational diabetes, preeclampsia,
miscarriage, and fetal malformations, which may be a result of an altered intrauterine environment. Maternal obesity can alter exposure of signaling molecules such as cortisol and proinflammatory cytokines, which can alter environmental inputs to the fetus in utero. Fetal intrauterine exposures can program long-term physiological and psychological outcomes through a process known as fetal or developmental programming. In addition to lasting physiological changes, maternal obesity has been shown to significantly alter psychological and neurodevelopmental outcomes in offspring.

Assessing dyadic mother-child interactions and the role that both mother and child behaviour play on childhood obesity is crucial in considering the intergenerational transmission of obesity. Temperament, which refers to innate differences in behavioural style that are distinct from the child's earliest years, may predict social and overall development of the child. Child temperament can also influence parenting and parent behaviour. Differing dimensions of temperament may affect how the parent and child or infant interact, how the parent soothes the child, and have been proposed as possible susceptibility factors that could predict feeding behaviors and potentially obesity risk. Infant temperament at 6 months of age was found to predict obesity risk up to 6 years of age dependent on the mother's sensitivity levels, further indicating a dyadic interaction associated with child health. Rothbart's theory outlines three broad dimensions of temperament: Surgency, Negative Affectivity, and Effortful Control. Surgency is characterized by impulsivity, high intensity pleasure, and activity; Negative Affect is characterized by discomfort, sadness, fear, and anger; Effortful Control is characterized by low intensity pleasure, smiling, inhibitory control, perceptual sensitivity, and attentional control. Surgency and Negative Affect scores have been associated with obesogenic eating behavior in preschool-aged children, increasing their obesity risk. Specifically, higher surgency may lead to higher reward response and greater pleasure from palatable foods. Negative Affect may be associated with angry reactions from the child when denied palatable foods in favor of healthier food options. Maternal pre-pregnancy body mass index (BMI) has been shown to be associated with temperament in 2-year-olds as well as fetal programming of metabolic diseases and intergenerational transfer of obesity risk; however, it is unclear whether temperament mediates this transmission of obesity risk.

The current study investigated: (1) the association between pre-pregnancy BMI and child zBMI at 4 years of age, and (2) whether child Surgency scores at 3 years of age mediated this association. We hypothesized that child temperament assessed by their positive affectivity/surgency scores mediated the association between maternal pre-pregnancy BMI and offspring zBMI at 4 years of age. To our knowledge, this is the first study to analyze child temperament, maternal environment, and the association with highly accurate in-clinic child BMI z-score measures.

**Methods**

**Study Design and Population**
Data was accessed from the Alberta Pregnancy Outcomes and Nutrition (APrON) study, a longitudinal prospective pregnancy cohort that recruited 2189 women from Alberta between 2009 and 2012. Pregnant women > 16 years, gestational age < 27 weeks were eligible. Data from only one infant per pregnant woman was included in the study. Delivery data was obtained from the child’s birth record (administrative data). For the current study, we included all mother-infant dyads that had completed parent-reported temperament assessments and BMI data (n = 408). An in-person assessment allowed us to use highly accurate clinical measurements to determine BMI z-score. Specifically, at 4 years of age, children attended an in-person assessment visit and trained staff measured the children's height to the nearest 0.1 cm and weight to the nearest 0.01 kg. Reported values were the average of triplicate measurements. This study was approved by the University of Calgary Health Research Ethics Board and the University of Alberta Health Research Ethics Biomedical Panel. Written informed consent was obtained from women at enrollment and prior to the child in-person assessment visit at 4 years of age.

Outcomes

Body mass index was calculated as the child’s weight in kilograms divided by height in meters squared based on measurements obtained by an in-person assessment visit at 4 years of age. Age- and sex-specific BMI z-scores were calculated using the World Health Organization’s growth chart standards using their “igrowup” package for SPSS. At 3 years of age, infant temperament was assessed and scored using the Child Behavior Questionnaire Very Short Form (CBQ-VSF). The CBQ-VSF has demonstrated satisfactory internal consistency and criterion validity to the CBQ in similar cohorts, and is able to assess child temperament on three broad dimensions: Surgency (i.e., the tendency to approach new experiences in an energetic and positive way), Negative Affect (i.e., the tendency to be sad, irritable, or easily frustrated), and Effortful Control (i.e., the ability to control one's behavior, regulate emotions, and pay attention). Each dimension was assessed by a list of statements where parents assign a value of 1 to 7, ranging from “extremely untrue of your child” to “extremely true of your child”.

Covariates

Maternal age, race and ethnicity, education, income, and occupation, were collected at enrollment in the study at < 27 weeks gestation. Maternal pre-pregnancy BMI was calculated based on height and weight measured at first study visit. At each visit, trained staff measured the participant's weight to the nearest 0.01 kg and height to the nearest 0.1 cm. Total gestational weight gain was calculated as the difference between the reported pre-pregnancy body weight and the highest self-reported weight during pregnancy collected three months postpartum as previously described. Maternal postpartum anxiety was measured through the Symptom Checklist-90 (SCL) scale and maternal postpartum depression was measured through the Edinburgh Postnatal Depression Scale (EPDS), both at 12 weeks postpartum. The Home Observation for Measurement of the Environment-Short Form (HOME-SF) inventory, which generates separate scores for Cognitive Stimulation and Emotional Support, was utilized to assess neurodevelopmental support for children.

Statistical Analysis
Descriptive statistics for mother and infant characteristics are shown as frequencies and proportions or means, when applicable. A Pearson's correlation was run to assess the relationship between BMI z-score at 4 years of age, maternal pre-pregnancy BMI, and positive affectivity/surgency. Our hypothesis was tested using Hayes' conditional process modeling\textsuperscript{33} using a linear regression-based PROCESS macro (5000 bootstraps and 95% confidence interval) in SPSS version 26 from IBM (New York, NY, USA). The model was adjusted for covariates including maternal pre-pregnancy BMI, 12 week postnatal anxiety and depression, child cognitive and emotional support, and total gestational weight gain. Data is displayed as the unstandardized beta coefficient, standard error of the unstandardized beta coefficient, and the upper and lower 95% confidence intervals for the unstandardized beta coefficient. Statistical significance was set at \( P < 0.05 \).

**Results**

**Demographics**

Table 1 presents descriptive data on the current sample. The mean age of mothers was 32.1 ± 3.9 years, majority had an annual household income \( \geq \$70,000 \) CAD (80.9%), were married (85.3%), and had a university education (73.7%).

Bivariate correlations between study variables are provided in Table 2. BMI z-score was positively correlated with Positive Affectivity/Surgency and maternal pre-pregnancy BMI. Pre-pregnancy BMI was positively correlated with Positive Affectivity/Surgency, income, prenatal depression and anxiety, and negatively correlated with education. Level of education was negatively correlated with maternal anxiety and depression scores, and positively correlated with child emotional and cognitive support. Prenatal anxiety and depression were positively correlated, and child emotional and cognitive support were positively correlated.

**Associations between pre-pregnancy BMI, temperament, and child zBMI**

There was a direct effect of pre-pregnancy BMI in the unadjusted (\( \beta = 0.0192 \) (SE = 0.009), 95% CI [0.002, 0.037], \( p = 0.030 \)) and the adjusted (\( \beta = 0.023 \) (SE = 0.011), 95% CI [0.001, 0.045], \( p = 0.043 \)) linear regression models. The unadjusted regression model was significant (\( p = 0.007 \)), and pre-pregnancy BMI (\( \beta = 0.019 \) (SE = 0.009), 95% CI [0.002, 0.037], \( p = 0.030 \)) and child Surgency (\( \beta = 0.117 \) (SE = 0.057), 95% CI [0.005, 0.230], \( p = 0.041 \)) were significant predictors of increased zBMI at 4 years of age. Adjusting for income, education, maternal depression and anxiety, emotional and cognitive support for the child, and total gestational weight gain attenuated the associations between pre-pregnancy, child Positive Affectivity/Surgency and zBMI (\( p = 0.068 \)). zBMI was positively correlated with Surgency (\( r = 0.109, p = 0.028 \)). Surgency was negatively correlated with Effortful Control scores (\( r = -0.102, p = 0.039 \)). Negative Affect and Effortful Control were not significant mediators of zBMI score, nor did these dimensions of temperament predict child zBMI score.
Mediation by child Positive Affectivity/Surgency levels

There was a direct effect of maternal pre-pregnancy BMI in the unadjusted ($\beta = 0.0167$ (SE = 0.008), $p = 0.029$) and the adjusted model ($\beta = 0.023$ (SE = 0.010), $p = 0.025$) on zBMI in 4-year-old children (see Figs. 1 and 2). In the adjusted model, the bootstrapped indirect effect of pre-pregnancy BMI on child zBMI through positive affectivity/surgency scores as a mediator was significant ($\beta = 0.003$, 95% CI [0.0001, 0.008]). This suggests that the effect of pre-pregnancy BMI on child zBMI may be via child temperament. Specifically, a higher pre-pregnancy BMI is associated with higher surgency scores at 3 years of age, which is associated with higher zBMI at 4 years of age. This model accounted for 5.6% of the variance in zBMI score at 4 years. In the adjusted model, pre-pregnancy BMI showed positive associations with positive affectivity/surgency scores at 3 years ($\beta = 0.023$ (SE = 0.010), 95% CI [0.003, 0.044], $p = 0.025$). Positive affectivity/surgency scores ($\beta = 0.134$ (SE = 0.066), 95% CI [0.005, 0.264], $p = 0.042$) significantly predicted zBMI scores at 4 years of age.

Discussion

Our findings from the APrON cohort indicated that the positive association between pre-pregnancy BMI and child zBMI at 4 years of age was mediated by the child’s temperament at three years, specifically Surgency. These findings suggest that higher pre-pregnancy BMI is associated with increased positive Affectivity/Surgency scores in toddlers, which could subsequently be associated with increased zBMI at 4 years of age. To our knowledge, this is the first paper that analyzes child Surgency as a mediator in the association between pre-pregnancy BMI and child zBMI.

In infants and toddlers, greater approach to novelty, a facet of Surgency, was shown to be related to positive responses to new foods, which may lead to a perception of higher reward from novel foods\(^{35}\). Similarly, another study found that surgency in 6-month-old infants was associated with increased weight-for-length changes, but only if their parents turned to food as a soothing mechanism\(^{19}\). Infant surgency and negative affect are positively associated with the use of food to calm the infant\(^{36}\). A study in Norwegian 4-year-olds followed prospectively up to 10 years of age found that all three dimensions of temperament predicted various responses to food: negative affect predicted higher food responsiveness and emotional under- and over-eating, effortful control predicted slower eating pace and better food regulation, and Surgency predicted higher food approach behaviors\(^{37}\).

We found that maternal pre-pregnancy BMI was a significant predictor of temperament, specifically surgency in 3-year-olds. A previous observational study found pre-pregnancy BMI as a moderator of child eating behaviors and Negativity temperament, whereby higher pre-pregnancy BMI and children with high Negativity and low eating slowness had the greatest rapid weight gain\(^{34}\). We also found that Surgency was a significant predictor of zBMI score in 4-year-olds. Similarly, a prospective cohort study that analyzed infant temperament in association to pediatric obesity at ages 2 to 5 found that high soothability scores in infancy was associated with 2.5-fold increased odds of obesity\(^{38}\). Soothability was
also associated with early introduction of sugar sweetened beverages and complementary food before 6 months of age; breastfeeding was protective against the onset of pediatric overweight and obesity\textsuperscript{38}. Higher surgency has also been associated with obesogenic eating behaviors in preschool-aged children, which is consistent with our finding that it mediated the association between maternal pre-pregnancy BMI and higher zBMI in children at 4 years of age\textsuperscript{23}. A previous study showed that in children aged 3–8 years old, higher child BMI was related to more food approach eating behaviors, and emotional children may exhibit altered eating behaviours\textsuperscript{39}. Another study found that the behaviour of restrained eating predicted weight gain\textsuperscript{40}. Restrained eating was more prevalent in girls who were more sensitive to reward, and in boys who were more sensitive to punishment, which are both types of reactive temperament\textsuperscript{40}.

Compared to mothers with a BMI in the normal range, maternal obesity has been linked to lower quality mother-child attachment, which was then subsequently linked to higher BMI percentile in children\textsuperscript{41}. Higher maternal BMI was also associated with behaviour at 2 years of age as measured by higher scores on the externalizing problems scale on the Child Behavior Checklist\textsuperscript{25}. In the current study, we analyzed temperament, which has been shown to predict behaviour\textsuperscript{42}. While the current study shows the mediating effect of temperament on child zBMI, and there are studies demonstrating that surgency is associated with higher zBMI, the mechanism by which maternal pre-pregnancy BMI affects temperament remains to be determined. One potential explanation for pre-pregnancy BMI affecting temperament may be differences in intrauterine and delivery-associated glucocorticoid exposure. Glucocorticoids such as cortisol, corticosterone, and 11-dehydrocorticosterone are crucial for growth and development, and women with obesity are found to have lower circulating glucocorticoids during pregnancy\textsuperscript{43}. Another potential mechanism may be differences in the gut microbiota, which has been shown to affect the brain via the microbiota-gut-brain axis, as well as affect energy harvest and metabolic health\textsuperscript{44}. Infants of women with obesity tend to harbor similar ‘obesogenic’ microbiota, which have enhanced capabilities for energy harvest and carbohydrate utilization\textsuperscript{45}, and ultimately increase obesity risk in the infant. Furthermore, there is increasing literature showing that certain intestinal bacterial species may contribute to child temperament. In a cohort of infants aged 9 to 54 days of age, \textit{Bifidobacterium} was enriched in infants who showed high negative emotionality and regulation/orienting\textsuperscript{46}. In 1-year-old infants, \textit{Bifidobacterium} was positively correlated to soothability, and cuddliness was negatively correlated to \textit{Hungatella}\textsuperscript{47}. Christian \textit{et al.} also found consistent associations between phylogenetic diversity, beta diversity, and certain bacterial abundances with surgency/extraversion in children 18 to 27 months of age\textsuperscript{48}.

The current study has several strengths including the inclusion of a validated measure of temperament at 3 years, and highly accurate in-person measurements of child height and weight for zBMI calculation at 4 years of age. We were able to adjust for sociodemographic characteristics, maternal mental health, and child environmental support, as well as gestational weight gain to isolate the effects of maternal BMI and temperament on child zBMI. Previous studies that have reported associations between surgency and positive response to food often consider parenting techniques and maternal sensitivity as covariates\textsuperscript{21,23}.
A strength of our study was that we used the HOME scale, which provides a broad assessment of the home environment. Our cohort is a relatively homogenous group of higher socioeconomic status and white participants, which may limit generalizability. Furthermore, having only maternal reports of temperament may introduce bias. Future studies may want to employ in-clinic assessments, where a third-party observer can also assess temperament.

In conclusion, we showed that the association between maternal pre-pregnancy BMI and child zBMI score was mediated by higher surgency scores on the CBQ in 3-year-old children. We also showed that there were both direct and indirect links between surgency and zBMI score. Future studies should consider child temperament and behaviour when studying child obesity risk. Child temperament may be a powerful resource as an early intervention to unhealthy eating behaviors and preventing childhood obesity.

Declarations

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DISCLOSURE: The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS: NAC, GFG, and RAR conceived the study. NAC and GFG performed data analysis. NAC wrote the first draft of the manuscript. RAR, DD, and GFG secured funding. RAR had ultimate responsibility for the work. All authors reviewed the paper and approved of the submitted and published version.

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Competing Interests

The authors declare no conflicts of interest.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

References


**Tables**

Table 1. Demographic and clinical characteristics of the current cohort (n=408).
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**Table 2.** Bivariate correlations between child and maternal variables and BMI z-score

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<td>.071</td>
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<td>.067</td>
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<td>-.102*</td>
<td>.109*</td>
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<td>.154**</td>
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<td>.150**</td>
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<td>.263**</td>
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<td>.150*</td>
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Note * p < 0.05, ** p < 0.01, 2-tailed analysis
Figures

Figure 1
Unadjusted model for the association between Pre-pregnancy BMI, Positive Affectivity/Surgency scores, and zBMI at 4 years of age.

Figure 2
Adjusted model for the association between Pre-pregnancy BMI, Positive Affectivity/Surgency scores, and zBMI at 4 years of age. Adjusted for maternal gestational weight gain, income, education, anxiety and
depression, and child cognitive and emotional support.