Maternal Prepregnancy Overweight and Offspring Fatness and Blood Pressure: Role of Physical Activity

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The purpose of this study was to examine if offspring physical activity may affect the relationship between maternal overweight and offspring fatness and blood pressure (BP). Subjects included 144 maternal-child pairs (n = 74 boys and 70 girls, mean age = 7.3 yrs). Maternal prepregnancy BMI was determined by self-report. Offspring characteristics included resting systolic and diastolic BP, body fatness by dual energy x-ray absorptiometry, and moderate-to-vigorous physical activity (MVPA) using the Actigraph accelerometer. Children whose mothers were overweight or obese prepregnancy (Prepreg OW) were significantly larger and fatter than children from mothers with a normal prepregnancy BMI (Prepreg NORM). Prepreg OW children also had higher mean arterial pressure than Prepreg NORM children. BP values were not different across maternal Prepreg BMI/MVPA groups. Percent fat was significantly different across Prepreg BMI/MVPA groups. Prepreg OW children that did not meet the daily recommended value of MVPA were the fattest. Prepreg OW children that attained ≥60 min of MVPA/day had a mean percent body fat that was similar to Prepreg NORM children of either MVPA group.

It is often considered that the current pediatric obesity epidemic and adverse cardiovascular disease (CVD) risk factors such as elevated blood pressure (BP) are due to decreased habitual physical activity, increased television viewing, poor diet quality and increased total daily caloric intake (6,15,28). However, epidemiologic data indicate that the secular increase in pediatric obesity and emergence of the metabolic syndrome cannot be fully explained by physical activity and diet alone.
These papers have posited that the etiology of the obesity-hypertensive phenotype during childhood is quite complex and may involve genetic and environmental factors operating during both the prenatal and postnatal periods (4,9,16).

Recently, there has been an emerging interest in the role of prenatal factors and the intrauterine environment on offspring obesity and CVD risk factors (1,13). In particular, maternal obesity before and during pregnancy has been shown to be related to offspring obesity and CVD risk factors in both animals (27) and humans (2,11,12,14,20,25). These findings are a concern given the rising prevalence of obesity among women of childbearing age (17).

Physical activity is considered a cornerstone in the prevention and treatment of obesity and hypertension. Several studies have examined the association between physical activity and adiposity or BP during childhood (8). However, the role of physical activity on fatness and BP in youth born to mothers who were obese at conception has not been considered. This is an important relationship to understand given that physical activity may differentially influence adiposity and BP in youth exposed to a prenatal environment of an obese mother compared with those born to normal weight mothers. Therefore, the primary purpose of this study was to examine the combined influence of maternal prepregnancy weight status and offspring physical activity on offspring fatness and BP.

**Methods**

**Subjects**

This article represents a secondary data analysis of a project aimed at investigating the longitudinal development of adiposity and blood pressure in young children. Therefore, the recruitment of subjects focused on young children rather than maternal-child pairs. The participants in this article included 144 maternal-child pairs (n = 74 boys and 70 girls, mean age = 7.3 yrs) from a rural U.S. Midwestern community (pop. 30,000). The child participants were recruited through written and/or verbal advertisements. Parental consent was obtained from all participants, and the procedures were also explained to the child participants. The study protocol was approved by the University of Nebraska at Kearney Institutional Review Board.

Some general characteristics of the mothers include: age, 30 ± 4 yrs; height, 166 ± 6 cm; prepregnancy weight, 64 ± 11 kg; prepregnancy BMI, 23.2 ± 4.0 kg/m². All of the mothers had a high school education, and 75% were a college graduate (of which 31% had some postgraduate education). Seventy percent breast-fed their offspring for a mean of 20 ± 20 weeks.

**Measurements**

Maternal prepregnancy BMI was determined by self-reported height and weight, and used to create two categories: prepregnancy normal weight (BMI < 25.0 kg/m²; Prepreg NORM) and overweight (BMI ≥ 25.0 kg/m²; Prepreg OW). It is known that the self-reporting of height and weight is problematic. In general, women tend to overestimate height and underestimate weight (10). To our knowledge, no study has specifically addressed the validity of recalled prepregnancy weight compared with direct measure of prepregnancy weight. One study found a difference of about 2
kg between self-reported prepregnancy weight and estimated prepregnancy weight (34). In addition, results from the Nurses’ Health Study II comparing recalled weight at age 18 with records from physical examinations conducted at college or nursing school entrance indicate that the participants slightly under-reported weight at age 18 (mean difference = 1.4 kg; 31). The mean body mass index (BMI) values were 21.6 kg/m² for BMI calculated using recalled weight and 22.1 kg/m² using weight from medical records with a the correlation between the two measures of 0.84.

Offspring characteristics included body fatness, resting systolic and diastolic BP, and moderate-to-vigorous physical activity. Whole-body dual energy x-ray absorbtiometry (DXA) scans were performed with the subject in light clothing while lying supine using a Lunar DPX-L densitometer (Lunar Radiation Corporation, Madison, WI, USA). Percent body fat (%BF) was determined using the pediatric medium scan mode (software version 1.5d). The Lunar DPX-L densitometer has previously been cross-validated using the pig carcass in the pediatric weight range (26). Reliability between scans was achieved using a phantom calibration. Resting BP was measured in accordance with standard procedures and recommendations (21). Appropriate cuff size was determined by measuring the circumference of the right upper arm at its largest point. Resting systolic (SBP) and diastolic (DBP) blood pressure was measured by sphygmomanometry after the subject was seated for 10 min. The mean arterial pressure (MAP) was calculated as: (SBP-DBP/3) + DBP. Three measurements were taken at 1-min intervals, and the mean of the three values were used for data analysis. Habitual physical activity was assessed with the Manufacturing Technology, Inc. (MTI) Actigraph (model #AM7164, Fort Walton, FL) for seven consecutive days. The MTI Actigraph is a small (5.1 × 3.8 × 1.5 cm), light weight (45g) uniaxial accelerometer designed to detect vertical acceleration ranging in magnitude from 0.05 to 2.00 G with a frequency response of 0.25–2.50 Hz. For the current study, a 60-s epoch was used. To be included in the analysis, children were required to wear the MTI physical activity monitor for at least three full weekdays and one weekend day. To be considered a full day, the monitor had to be worn for at least 480 min (8 hr). If this was not achieved, that particular day was excluded from the data analysis. Parents/guardians were asked to fill out a daily log sheet in conjunction with each child wearing a physical activity monitor to determine when the monitor was removed for bathing, swimming or forgotten. To ensure accuracy, each day of the minute-by-minute physical activity data were downloaded and manually checked against the daily physical activity log sheet by the investigator. Participants wore the physical activity monitors for 681 ± 72 min per day for 6 ± 1 days. The monitors were taken off to swim an average of 34 ±38 min per day as reported by parents and cross referenced with data. Summing the 24, 60-min time blocks comprising each day, generated daily total counts. Activity counts were converted to counts/min based on the total daily time the unit was worn. Moderate to vigorous physical activity (MVPA) was calculated as the total amount of time each day spent in moderate plus vigorous activity using a cut point developed through a calibration study that employed direct observation as the criterion measure (32). In the calibration study, children (ages 8–12 years) were observed during two separate sessions while going through a series of semistructured (session 1, used for calibration) and free-living activities (session 2, used for cross-validation). The cut point was determined using receiver operator characteristic (ROC) curves that identified the count that most accurately corresponded with the observed transition
to moderate physical activity (the threshold of MVPA). The process yielded a value of 2172 counts/min with reported sensitivity and specificity of 95.9 and 87.6, respectively (32). Children were classified into two groups based on whether they met the recommended level of MVPA per day (60 min of MVPA per day; 29).

Statistical Analysis

Descriptive statistics were calculated for all variables and reported as mean ± SD. Initial differences between groups (prepregnancy BMI and offspring MVPA) were examined by independent \( t \) tests. Analysis of covariance was used to determine differences in offspring fatness and BP by prepregnancy BMI and offspring MVPA groups independently and by cross-tabulation (e.g., prepregnancy normal weight and child meets MVPA guideline, etc.). Covariates in the offspring fatness models were age, sex, and height. Covariates in the offspring BP models were age, sex, height, and percent fat. Values from ANCOVA are reported as mean ± SE. A \( p \)-value of <0.05 was used for statistical significance. Statistical analyses were conducted using SPSS version 16.0.

Results

Descriptive statistics of the total sample and by mother’s prepregnancy BMI (normal weight or overweight/obese) and child’s level of MVPA (≥60 min of MVPA/day or <60 min of MVPA/day) are shown in Table 1. Children whose mothers were overweight or obese prepregnancy (Prepreg OW) had significantly greater body mass, BMI (27.1 ± 10.6 v. 25.4 ± 7.5 kg and 17.4 ± 3.2 v. 16.2 ± 2.3 kg/m², respectively) and body fatness (29 ± 10% v. 26 ± 7%, respectively) than children from mothers with a normal prepregnancy BMI (Prepreg NORM). These differences remained when age, sex, and height were controlled. The mean BP values were higher in Prepreg OW children compared with Prepreg NORM children, and the difference in MAP was statistically significant after controlling for age, sex, height, and %BF (83.2 ± 0.9 v. 81.2 ± 0.5 mmHg, respectively). MVPA was similar (about 65 ± 30 min/d) between Prepreg OW children compared with Prepreg NORM children. Percent body fat was significantly higher in children who did not meet the daily recommended level of MVPA (28 ± 9%) compared with those who did meet the daily recommended level of MVPA (24 ± 6%). BP was not significantly different between MVPA groups.

Although BP values were not different across the four maternal Prepreg BMI/MVPA groups, %BF was significantly different across Prepreg BMI/MVPA groups (Table 2). Prepreg OW children that did not meet the daily recommended value of MVPA (<60 min/day) were the fattest (32 ± 2%). Prepreg OW children that attained ≥60 min of MVPA/day had a mean percent body fat (26 ± 2%) that was similar to Prepreg NORM children of either MVPA group (≥60 min = 24 ± 1% and <60 min = 26 ± 1%).

Discussion

This study provides a novel approach to examining the potential role of physical activity on the adiposity-BP phenotypes of offspring born to overweight mothers. Although previous studies showed the adverse effects of prepregnancy overweight
Table 1  **Physical Characteristics of the Sample**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mother’s prepregnancy BMI</th>
<th>Child’s MVPA Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal (&lt;25 kg/m²)</td>
<td>Overweight/Obese</td>
</tr>
<tr>
<td></td>
<td>n = 108</td>
<td>(≥25k g/m²) n = 36</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>7.4 ± 2.1</td>
<td>6.9 ± 1.9</td>
</tr>
<tr>
<td>Ht (cm)</td>
<td>124.1 ± 13.2</td>
<td>122.4 ± 13.8</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>25.4 ± 7.5</td>
<td>27.1 ± 10.6*</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>16.2 ± 2.3</td>
<td>17.4 ± 3.2*</td>
</tr>
<tr>
<td>DXA (% fat)</td>
<td>26.0 ± 7.5 (n = 107)</td>
<td>28.9 ± 9.6*</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>104.2 ± 8.8</td>
<td>106.6 ± 9.1</td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>69.3 ± 7.0</td>
<td>72.2 ± 7.2</td>
</tr>
<tr>
<td>MAP (mmHg)</td>
<td>80.9 ± 6.7</td>
<td>83.7 ± 7.0</td>
</tr>
<tr>
<td>MVPA (min/day)</td>
<td>64.4 ± 32.8 (n = 94)</td>
<td>65.5 ± 28.4 (n = 30)</td>
</tr>
</tbody>
</table>

*Note.* Values are mean (SD) for individuals grouped based on mother’s prepregnancy BMI, for the total sample also showing the range of values, and by MVPA group.

*P < .05 for group difference

Ht = height; BMI = body mass index; DXA = percent body fat determined by dual energy x-ray absorptiometry; SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial pressure; MVPA = moderate to vigorous physical activity.
<table>
<thead>
<tr>
<th>Child's MVPA Level</th>
<th>≥60 min/day n = 49</th>
<th>&lt; 60 min /day n = 45</th>
<th>≥60 min /day n = 12</th>
<th>&lt; 60 min /day n = 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>1SBP (mmHg)</td>
<td>104.2 (1.0)</td>
<td>105.1 (0.9)</td>
<td>107.9 (1.5)</td>
<td>102.6 (1.9)</td>
</tr>
<tr>
<td>1DBP (mmHg)</td>
<td>70.3 (0.9)</td>
<td>69.3 (0.9)</td>
<td>71.0 (1.4)</td>
<td>71.0 (1.8)</td>
</tr>
<tr>
<td>1MAP (mmHg)</td>
<td>81.6 (0.8)</td>
<td>81.2 (0.7)</td>
<td>83.3 (1.2)</td>
<td>81.5 (1.5)</td>
</tr>
<tr>
<td>2DXA (% fat)</td>
<td>24.4 (1.0)</td>
<td>26.6 (0.9)</td>
<td>26.1 (1.5)</td>
<td>32.3 (1.9)*</td>
</tr>
</tbody>
</table>

Note. Values are estimated mean (SE).
1controlling for age, sex, height, and percent fat.
2controlling for age, sex, and height
* significantly different from all other groups; P < .05

BMI, body mass index; MVPA, moderate to vigorous physical activity; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure
Maternal Overweight and Offspring Fatness

on offspring adiposity and CVD risk factors, it was unknown if offspring physical activity could attenuate these adverse characteristics. The results indicate that MVPA during childhood is associated with, to a certain extent, the adverse effects of maternal overweight on childhood obesity but not resting BP. The results are important to consider in the context of understanding the development of the obesity-hypertension phenotype and its response to physical activity, particularly in light of the increasing number of overweight women of childbearing age.

Our results confirm those of previous studies which show that prepregnancy overweight is an important factor in the development of offspring adiposity and BP (2,11,12,14,20,25). The trends in the results for BP were also independent of child fatness, which suggests that prepregnancy BMI may have either a direct or indirect effect on offspring BP. The effect of prepregnancy obesity on these traits may be due to genetics, factors occurring during the intrauterine period, or the shared environment during postnatal life. The estimated heritability of adiposity measures range from 25 to 40% and several studies have shown an association of maternal BMI (and paternal BMI) with offspring BMI (3); however, not all of these studies consider maternal prepregnancy BMI. This idea has been expanded and proposed as the fetal overnutrition hypothesis which suggests that maternal obesity leads to an intrauterine environment that stimulates increased obesity among their offspring and subsequent intergenerational acceleration of obesity levels (20). However, two studies have refuted this hypothesis by showing that the magnitude of the association between maternal and paternal BMI with offspring BMI is similar (5,18). Nonetheless, although prepregnancy BMI does not directly indicate fetal overnutrition, prepregnancy obesity has been related to poor diet during pregnancy (19). It is also possible that prepregnancy overweight is linked to a disruptive hormonal milieu of the developmental biology linked to appetite, energy balance, and pathophysiology of obesity and vascular health (e.g., BP, vascular wall structure and function; 27). Although a previous animal study showed that maternal overnutrition was associated with lower offspring locomotor activity compared with offspring born to adequately nourished mothers (27), we did not show a difference in MVPA between offspring born to overweight and normal weight mothers. Unfortunately, we did not measure dietary consumption. Finally, the aforementioned biological basis of this relationship may also involve epigenetic mechanisms (13,33).

The relationships between offspring MVPA, body fat and BP were similar to the well-documented trends in youth (8). In general, MVPA showed a small-to-modest association with body fatness and was not significantly related to resting BP. The mean level of daily MVPA was 65 ± 32 min per day with about half of the children obtaining the recommended 60 min/day. These results are similar to those from the 2003–04 NHANES study which found 42% of U.S. children aged 6–11 years met the current physical activity recommendations as measured by accelerometry (30). However, the primary purpose of this study was to examine how offspring physical activity may influence the relationship between maternal obesity and offspring fatness and BP. The results indicate that percent body fat but not BP values were different across the four maternal prepregnancy BMI/offspring MVPA groups. More specifically, prepregnancy OW children that did not meet the recommended daily value of MVPA (<60 min/day) were the fattest (32 ± 2%). Although this result was expected, it also signifies the importance of considering maternal obesity when assessing childhood obesity among inactive
youth, as inactive youth born to normal weight mothers had a mean %BF of 26 ± 1%. The results showing that prepregnancy OW children meeting the MVPA recommendation had a mean %BF that was similar to Prepreg NORM children of either MVPA group is also important clinically. Although these results suggest the importance of childhood physical activity in offspring born to overweight mothers, it remains to be determined if the %BF value and risk of obesity in active children born to overweight mothers differs from that of active children born to normal weight mothers.

This study is limited by the small sample size and mixed sample of boys and girls. In addition, the percentage of mothers who were overweight or obese before pregnancy is considerably lower (25%) than national estimates (65%; 22). Prepregnancy BMI was also calculated from self-reported height and weight. There are also several lifestyle factors (diet, etc.) during pregnancy that were not considered. Finally, the cross-sectional nature of our study limits inference about the direction of causality. Regardless of these limitations, this study provides a novel approach to examining the role of physical activity on child adiposity and BP by considering maternal prepregnancy weight status.

Typically, physical activity is considered one of the cornerstones in the amelioration of the pediatric obesity epidemic (6). However, this approach is limited to the postnatal period. There are perhaps important preventive implications in relation to maternal weight among women of childbearing age (23). The lack of recognition of the maternal-fetal origins of obesity may help explain why the approach of exercise can be ineffective in reducing adiposity to normal levels in obese children. There is clear evidence that environmental factors in utero are important to child health and create a new paradigm for prevention (4,24). The maternal-fetal and epigenetic evidence has created a cycle of intergenerational transmission of the obesity phenotype (4,24). However, this study indicates that adiposity can be attenuated by physical activity in children born to mothers who were overweight before pregnancy.

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