Maternal Prepregnancy Body Mass Index and Child Psychosocial Development at 6 Years of Age

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abstract

BACKGROUND: Both obesity and developmental disabilities have increased in recent decades. Limited studies suggest associations between maternal prepregnancy obesity and child neurodevelopment.

METHODS: The Infant Feeding Practices Study II, a US nationally distributed longitudinal study of maternal health and infant health and feeding practices, was conducted from 2005 to 2007. In 2012, mothers were recontacted for information on their children's health and development. We examined associations between maternal prepregnancy BMI and child psychosocial development in 1311 mother–child pairs included in this follow-up study. Children's development was assessed by maternal report of child psychosocial difficulties from the Strengths and Difficulties Questionnaire, past developmental diagnoses, and receipt of special needs services.

RESULTS: Adjusting for sociodemographic factors, children of obese class II/III mothers (BMI >35.0) had increased odds of emotional symptoms (adjusted odds ratio [aOR] 2.24; 95% confidence interval [CI], 1.27–3.98), peer problems (aOR 2.07; 95% CI, 1.26–3.40), total psychosocial difficulties (aOR 2.17; 95% CI, 1.24–3.77), attention-deficit/hyperactivity disorder diagnosis (aOR 4.55; 95% CI, 1.80–11.46), autism or developmental delay diagnosis (aOR 3.13; 95% CI, 1.10–8.94), receipt of speech language therapy (aOR 1.93; 95% CI, 1.18–3.15), receipt of psychological services (aOR 2.27; 95% CI, 1.09–4.73), and receipt of any special needs service (aOR 1.99; 95% CI, 1.33–2.97) compared with children of normal weight mothers (BMI 18.5–24.9). Adjustment for potential causal pathway factors including pregnancy weight gain, gestational diabetes, breastfeeding duration, postpartum depression, and child's birth weight did not substantially affect most estimates.

CONCLUSIONS: Children whose mothers were severely obese before pregnancy had increased risk for adverse developmental outcomes.

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WHAT'S KNOWN ON THIS SUBJECT: Both obesity and developmental disabilities have increased in recent decades; however, the full long-term effects of prepregnancy obesity on a child's psychosocial development remain unknown. Limited studies suggest associations between maternal prepregnancy obesity and child psychosocial development.

WHAT THIS STUDY ADDS: This study in 6-year-old children provides evidence that severe prepregnancy obesity is associated with adverse child psychosocial outcomes, including attention-deficit/hyperactivity disorder. These findings were not explained by many pregnancy and postpartum factors related to maternal obesity or child development.

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Both obesity and developmental disabilities have increased dramatically in recent decades.[1–4] By 2009, 20.5% of US women were obese at the start of their pregnancy, a 16.5% increase since 2003.[5] By 2006–2008, 15% of US children were diagnosed with a developmental disability, a 17% increase since 1997.[3]

Pregnancy obesity has been associated with increased systemic inflammation, altered endocrine responses, and insulin resistance.[6,7] Although associations between maternal obesity and pregnancy complications are well documented, less is known about longer-term child outcomes. There is growing concern about neurologic effects.[8,9] Recent epidemiologic studies suggest associations between prepregnancy obesity and various neurodevelopmental outcomes.[10–21] However, these studies were limited by small sample sizes, insufficient information on confounders and mediators, and imprecise neurodevelopment measures. Additionally, 1 study reported no association.[22]

Using a larger sample from a US longitudinal study than most previous studies, we addressed many previous study limitations. We examined associations between maternal prepregnancy BMI and subsequent child psychosocial development using multiple, complementary outcome measures: parent report of children's difficulties, specific developmental disability diagnoses, and receipt of special needs services. Thus, we expanded on many previous studies' findings that focused more narrowly on cognitive performance[10,13,14,17,21] and incorporated measures of developmental difficulties not solely dependent on a past diagnosis or parents specifically seeking services, but also measures based on parents' direct observations. Additionally, we examined the effects of numerous factors potentially in the causal pathway, including pregnancy weight gain, gestational diabetes, breastfeeding, and postpartum depression.

METHODS

Study Population

The Infant Feeding Practices Study II (IFPS II) includes participants from a nationally distributed consumer opinion panel, which followed mother–infant pairs from the third trimester of pregnancy through infants' first year of life.[23] Information on infants' feeding and health and mothers' health were collected from 2005 to 2007. All infants included in IFPS II were delivered at ≥35 weeks. Among 4902 pregnant women who began IFPS II, 3033 answered the neonatal (month 1) questionnaire and were contacted for the Year 6 Follow-Up (Y6FU) in 2012; 2958 mother–child pairs met eligibility criteria, and 1542 mothers (52.1%) completed the self-administered questionnaire on their child's health and development. Overall, Y6FU respondents were more likely than nonrespondents to be of higher socioeconomic status (SES), older, and white and to have received early prenatal care. However, respondents were not different from nonrespondents on employment status, parity, or prepregnancy BMI. Children of respondents had longer durations of breastfeeding and were less likely to receive public assistance than children of nonrespondents. There were no differences between the 2 groups on breastfeeding initiation, birth weight, or gestational age. Additional details on the IFPS II and Y6FU are published elsewhere.[23,24]

Maternal Prepregnancy BMI

The IFPS II collected data on mother's prepregnancy height and weight via maternal report. Prepregnancy BMI was calculated and categorized: underweight (BMI <18.5), normal weight (BMI 18.5–24.9), overweight (BMI 25.0–29.9), obese class I (BMI 30.0–34.9), and obese class II/III (BMI ≥35.0).[25]

Child Psychosocial Development at Age 6

Strengths and Difficulties Questionnaire Scores

The Y6FU included the Strengths and Difficulties Questionnaire (SDQ), a behavioral screening questionnaire consisting of 25 attributes subdivided into 5 subscales: emotional symptoms, conduct problems, hyperactivity, peer problems, and prosocial behavior.[26] Mothers indicated how much each attribute pertained to their child during the past 6 months (not true, somewhat true, and certainly true). Each attribute was thus scored as 0 to 2, and each subscale, based on the compilation of 5 individual attributes, was scored as 0 to 10. Subscale scores were categorized as low, moderate, and high difficulties based on established criteria.[27,28] The specific cutoff points used to distinguish low, moderate, and high difficulties varied for each subscale; they were chosen based on empirical assessment to correspond to specific frequency distributions for each subscale in a US population-based sample.[27] The total difficulties score was the sum of 4 subscales; prosocial behavior (the only positive scale) was not considered in the total difficulties calculation.[26] The total difficulties score was categorized analogously to the subscale scores. In our final analyses, we dichotomized 4 SDQ subscale scores and the total difficulties score as low versus moderate/high difficulties. We subsequently refer to children with moderate/high difficulties as simply having "difficulties." We dichotomized the prosocial behavior subscale score as high versus low/moderate difficulties.

Developmental Diagnoses

Mothers were asked whether their child had ever been diagnosed by

a doctor or other health professional with attention-deficit (hyperactivity) disorder (ADD/ADHD), autism or developmental delay (autism/DD), depression or anxiety, or hearing problems. A diagnosis of autism/DD was included as a single item in the survey because of sample size constraints; thus, we could not examine the 2 diagnoses separately.

Receipt of Special Needs Services

Mothers also indicated special needs services their child received during the past school year: speech or language therapy; occupational therapy or other therapy for help with handwriting or motor skills; special instruction or help in ≥1 school subject; special services for vision or hearing problems; psychological services or counseling because of a problem with emotions, behavior, or socialization; behavioral support, such as behavior management plan or individual classroom support; other services; or no services received. We assessed each service separately, and we created a composite variable, receipt of any special needs service.

Covariates

Covariates were chosen a priori based on previous research examining maternal weight and child development associations. Potential confounders included maternal age, race or ethnicity, marital status, education level, poverty-to-income ratio, parity, smoking during pregnancy, child gender, child's current weight (via maternal report), and level of child's enrichment activities. We dichotomized "any" enrichment versus "none" based on whether mothers reported reading aloud to their child ≥3 times per week, child participated in special lessons or organizations, or both.

Potential causal pathway factors included pregnancy weight gain, gestational diabetes, breastfeeding duration, postpartum depression, and child's birth weight. Mother's pregnancy weight gain was categorized as inadequate, adequate, and more than adequate based on 2009 Institute of Medicine guidelines.[29] Breastfeeding was categorized as never, <6 months, ≥6 months/exclusively <3 months, and ≥6 months/exclusively ≥3 months. Child's birth weight for gestational age was calculated according to a national reference[30] and categorized as small (<10th percentile), appropriate (10th–90th percentile), and large for gestational age (>90th percentile). Postpartum depression was based on the Edinburgh Postnatal Depression Scale.[31] Because ∼10% of mothers were missing responses to postpartum depression, we created a separate "not-specified" category to maximize model sample sizes. In addition to postpartum depression, we assessed maternal history of any psychiatric condition; however, we included only the more specific and proximal outcome, postpartum depression, in our final analyses because the 2 variables were correlated and the findings using each variable were analogous.

Statistical Analyses

Our final sample sizes varied by outcomes. Among the 1542 mother–child pairs in the Y6FU, 1241 mothers had complete prepregnancy BMI information and covariates to examine child's SDQ scores; 1311 had sufficient data to examine child's developmental diagnoses; and 1253 had sufficient data to examine child's receipt of special needs services. We also assessed the 1166 mother–child pairs with complete information on all 3 outcome types; findings were comparable to those from the aforementioned samples (data not shown). Thus, we present the findings based on the larger samples. We also compared the characteristics of the final analytic samples to mother–child pairs excluded from each outcome-specific analysis. Excluded mothers were more likely to be underweight or obese class I and less likely to be ≥30 years of age, married, a college graduate, and to have breastfed >6 months. Excluded children were more likely to have been small for gestational age and to have several neurodevelopmental outcomes.

We conducted bivariate analyses comparing the proportion of children with each developmental outcome (moderate/high difficulties for each SDQ domain, previous diagnosis of each developmental condition, and receipt of each special needs service) by maternal BMI. Stratified analyses were conducted to assess possible effect modifications between prepregnancy BMI and each of the covariates and between prepregnancy BMI and each of the potential causal pathway factors. We observed only variable estimates within gestational diabetes and birth weight strata; we assessed effect modification statistically for those 2 factors by using likelihood ratio tests.

By using multivariable logistic regression models, we found no evidence of multicollinearity between included variables for any model. For each outcome, 2 models were constructed: The first included maternal prepregnancy BMI and all potential confounders; the second included maternal prepregnancy BMI, all potential confounders, and all potential causal pathway factors. We conducted all analyses by using SAS 9.3 (SAS Institute, Inc, Cary, NC).

RESULTS

Before pregnancy, 4.0% of mothers were underweight, 45.8% were normal weight, 25.4% were overweight, 12.6% were obese class I, and 12.2% were obese class II/III. Maternal age was markedly lower for underweight mothers and notably higher for obese class II/III mothers than normal weight mothers (Table 1). Obese class II/III mothers had the highest proportions of high school education or less, inadequate

TABLE 1 Maternal and Child Characteristics by Maternal Prepregnancy BMI, IFPS II, United States, 2005–2007

	Total (n = 1311),[a]%[b]	Underweight (n = 52),%[b]	Normal (n = 600),%[b]	Overweight (n = 333),%[b]	Obese Class I (n = 166),%[b]	Obese Class II/III (n = 160),%[b]	P
Total		4.0	45.8	25.4	12.6	12.2	
Maternal characteristics							
Age, y							.01
18–24	13.7	23.1	14.2	12.9	12.1	11.9	
25–29	32.0	44.2	35.2	27.3	33.1	25.0	
30–34	33.3	19.2	32.5	36.3	30.7	36.9	
≥35	21.1	13.5	18.2	23.4	24.1	26.3	
Race or ethnicity							.25
White	87.4	82.7	86.0	88.6	90.4	88.8	
Black	3.3	1.9	2.8	4.2	2.4	4.4	
Hispanic	5.1	5.8	5.3	5.4	4.2	4.4	
Asian/Pacific Islander	2.5	5.8	3.8	0.9	1.8	0.6	
Other	1.7	3.9	2.0	0.9	1.2	1.9	
Marital status							.11
Married	84.4	75.0	85.3	85.0	87.4	80.0	
Unmarried	15.6	25.0	14.7	15.0	12.7	20.0	
Education							.001
High school or less	15.9	21.2	13.2	14.1	18.7	25.6	
Some college	36.7	36.5	34.5	38.1	39.8	38.8	
College graduate	47.4	42.3	52.3	47.8	41.6	35.6	
Percentage of poverty level							<.001
<185%	34.5	48.1	28.8	36.9	36.8	43.8	
≥185%	65.5	51.9	71.2	63.1	63.2	56.3	
Smoking during third trimester, no. cigarettes per day							.03
1+	6.9	17.3	5.5	6.9	7.8	8.1	
0	93.1	82.7	94.5	93.1	92.2	91.9	
Parity							.12
Primiparous	27.7	32.7	30.8	23.7	25.9	24.4	
Multiparous	72.3	67.3	69.2	76.3	74.1	75.6	
Pregnancy wt gain							<.001
Inadequate	19.9	26.9	21.2	12.6	14.5	33.8	
Adequate	32.6	38.5	41.3	27.0	21.1	21.3	
More than adequate	47.5	34.6	37.5	60.4	64.5	45.0	
Gestational diabetes							<.001
Yes	7.6	0.0	5.0	6.6	11.5	18.1	
No	85.4	94.2	89.0	86.8	75.9	75.6	
Don't know or not sure	7.0	5.8	6.0	6.6	12.7	6.3	
Breastfeeding							<.001
Never breastfed	12.9	17.3	10.3	12.3	11.5	23.8	
Breastfed <6 mo	35.9	30.8	33.7	36.4	42.2	38.8	
Breastfed ≥6 mo + exclusive <3 mo	28.4	30.8	29.2	29.4	27.7	23.1	
Breastfed ≥6 mo + exclusive ≥3 mo	22.8	21.2	26.8	21.9	18.7	14.4	
Possible postpartum depression							.24
Yes	19.9	30.8	19.7	17.1	18.1	25.0	
No	71.3	63.5	72.3	72.4	73.5	65.6	
Not specified	8.8	5.8	8.0	10.5	8.4	9.4	
Child characteristics							
Gender							.90
Male	49.9	51.9	49.7	51.7	47.0	49.4	
Female	50.1	48.1	50.3	48.4	53.0	50.6	
Birth weight							<.001
Small for gestational age	5.1	11.5	4.8	5.7	3.6	4.4	
Appropriate for gestational age	82.2	86.5	86.3	79.6	79.5	73.8	
Large for gestational age	12.7	1.9	8.8	14.7	16.9	21.9	
Current BMI (reported by mother)							<.001
Very underweight/underweight	9.8	23.1	11.7	7.2	7.8	6.3	
Average	84.4	76.9	85.7	85.0	87.4	78.1	
Overweight/very overweight	5.7	0.0	2.7	7.8	4.8	15.6	

TABLE 1 Continued

	Total (n = 1311),%[a,b]	Underweight (n = 52),%[b]	Normal (n = 600),%[b]	Overweight (n = 333),%[b]	Obese Class I (n = 166),%[b]	Obese Class II/III (n = 160),%[b]	P
Child enrichment							
None	6.5	1.9	5.3	8.7	7.8	6.3	.03
Read aloud ≥3 times per week or received special lessons	38.7	38.5	36.0	36.6	44.0	47.5	
Read aloud ≥3 times per week and received special lessons	54.8	59.6	58.7	54.7	48.2	46.3	

[a] This sample size represents mother–child pairs with complete information on covariates to examine child's developmental diagnoses; final analytic sample sizes vary based on the type of developmental outcomes. Approximately 3% of mothers were missing information on marital status and education level, and 2.7% were missing information on pregnancy weight gain.
[b] Percentages may not add to 100 because of rounding.

and more than adequate pregnancy weight gains, and gestational diabetes, and the lowest proportion of breastfeeding initiation. Underweight and obese class II/III mothers were more likely to have low incomes than other groups; underweight mothers were most likely to have smoked. Children of underweight mothers were most likely to have been small for gestational age; children of obese mothers (class I, II/III) were most likely to have been large for gestational age. Similarly, children of underweight mothers were most likely to be very underweight/underweight at age 6, and children of obese class II/III mothers were most likely to be overweight/very overweight. Child enrichment was comparable across groups.

Compared with children of normal weight mothers, children of obese class II/III mothers had significantly higher proportions of total difficulties (17.2% vs 8.8%), past diagnosis of ADD/ADHD (6.9% vs 2.0%), receipt of speech or language therapy (21.3% vs 11.4%), psychological services (9.3% vs 4.4%), and any special needs services (39.3% vs 23.8%) (Table 2). Stratified analyses indicated there was little variability in estimates within most subgroups. Although some variability was observed within birth weight and gestational diabetes subgroups, the interaction terms were not significant (data not shown).

In unadjusted analyses, children of obese class II/III mothers had increased odds of emotional symptoms, conduct problems, peer problems, and total difficulties compared with children of normal weight mothers (Table 3). Children of obese class II/III mothers also had increased odds of having past diagnoses of ADD/ADHD, autism/DD, receipt of speech or language therapy, psychological services, and any special needs services compared with children of normal weight mothers. Odds ratios (ORs) for these outcomes ranged from 1.71 to 3.62. Adjustment for confounders and potential causal pathway factors did not substantially affect most associations. However, the estimate for past diagnosis of autism/DD was less precise, and the association with conduct problems was notably attenuated.

DISCUSSION

By using data from a comprehensive US longitudinal study, we found that children whose mothers were severely obese before pregnancy were much more likely than children whose mothers were normal weight to have adverse developmental outcomes. These outcomes included several that were defined based on maternal report of children's behavioral attributes (emotional symptoms, peer problems, and a composite of total difficulties with emotions, conduct, hyperactivity, and peer relationships). This suggests that these findings were not merely the result of differential access to or use of diagnostic or developmental treatment services. Nonetheless, we additionally observed associations with several outcomes based on maternal report of past developmental disabilities diagnoses (ADD/ADHD, autism/DD), and receipt of special needs services (speech or language therapy and psychological services). Thus, the observed associations included outcomes meeting a certain threshold of functional impact that necessitated treatment and were clinically recognized. Our findings were not substantially changed after adjustment for potential confounders (family's SES, mother's smoking during pregnancy, and child's enrichment or current weight status). Nor were the findings explained by other factors potentially in the causal path between maternal obesity and child development (pregnancy weight gain, breastfeeding, postpartum depression, or birth weight). We observed statistically significant associations only between obese class II/III and developmental outcomes, suggesting a possible threshold effect. Nonetheless, for emotional symptoms, the point estimates also increased (albeit nonsignificantly) for the overweight and obese class I categories, suggesting a possible dose response.

Our findings are consistent with previous studies. Associations have been reported between prepregnancy obesity and intellectual disability,[12,16] lower cognitive performance,[10,13,14,17,21] ADHD,[11,19,20,32] and autism[15] in children. One null study was also reported; however, it was limited by

TABLE 2 Child's Psychosocial Development by Maternal Prepregnancy BMI, IFPS II, United States, 2005–2007

	Total (n = 1241),[a]%[b]	Underweight (n = 50),%[b]	Normal (n = 569),%[b]	Overweight (n = 311),%[b]	Obese Class I (n = 160),%[b]	Obese Class II/III (n = 151),%[b]	P
SDQ scores[c]							
Emotional symptoms							.06
Low	90.7	88.0	92.4	91.3	90.0	84.8	
Moderate/high	9.3	12.0	7.6	8.7	10.0	15.2	
Conduct problems							.15
Low	86.4	90.0	88.2	86.5	83.1	81.5	
Moderate/high	13.6	10.0	11.8	13.5	16.9	18.5	
Hyperactivity							.51
Low	83.1	90.0	83.7	83.0	82.5	79.5	
Moderate/high	16.9	10.0	16.3	17.0	17.5	20.5	
Peer problems							.09
Low	86.7	86.0	88.1	87.1	88.1	79.5	
Moderate/high	13.3	14.0	12.0	12.9	11.9	20.5	
Prosocial behavior							.25
High	93.5	96.0	93.5	92.3	96.9	91.4	
Moderate/low	6.5	4.0	6.5	7.7	3.1	8.6	
Total SDQ							.01
Low	90.5	96.0	91.2	92.0	90.6	82.8	
Moderate/high	9.5	4.0	8.8	8.0	9.4	17.2	

	Total (n = 1311),[a]%[b]	Underweight (n = 52),%[b]	Normal (n = 600),%[b]	Overweight (n = 333),%[b]	Obese Class I (n = 166),%[b]	Obese Class II/III (n = 160),%[b]	P
Child ever diagnosed with[d]							
ADD/ADHD	3.1	1.9	2.0	3.6	2.4	6.9	.03
Autism or developmental delay	1.9	3.9	1.7	1.8	0.0	4.4	.05
Depression or anxiety	1.3	1.9	1.2	0.9	0.6	3.1	.24
Hearing problems	3.6	1.9	3.2	2.7	5.4	5.6	.29

	Total (n = 1253),[a]%[b]	Underweight (n = 50)%[b]	Normal (n = 571)%[b]	Overweight (n = 322)%[b]	Obese Class I (n = 160)%[b]	Obese Class II/III (n = 150)%[b]	P
Current receipt of special needs services[e,f]							
Speech or language therapy	13.2	16.0	11.4	14.3	8.8	21.3	.01
Occupational or therapy for motor skills	4.3	6.0	4.7	3.4	1.9	6.7	.24
Special help in school projects	9.1	8.0	8.8	7.5	10.0	13.3	.33
Special services for vision or hearing	1.1	2.0	0.7	1.2	1.3	2.0	.67
Psychological services	4.6	4.0	4.4	4.4	1.9	9.3	.03
Support in classroom by assistant	2.5	0.0	2.8	2.5	0.6	4.0	.26
Other special services	1.4	0.0	1.6	0.9	1.3	2.7	.55
Received any of these	25.4	30.0	23.8	23.0	21.3	39.3	$<$.001

[a] This sample size represents mother–child pairs with complete information on covariates to examine child's developmental diagnoses; final analytic sample sizes vary based on the types of developmental outcomes.

[b] Percentages may not add to 100 because of rounding.

[c] These percentage distributions are based on 1241 mother–child pairs with complete information on covariates to examine child's SDQ scores.

[d] These percentage distributions are based on 1311 mother–child pairs with complete information on covariates to examine child's developmental diagnoses.

[e] These percentage distributions are based on 1253 mother–child pairs with complete information on covariates to examine child's current receipt of special needs services.

[f] "During this school year, has your 6-y-old received any of the following services?"

assessing all overweight and obese women as a single group.[22]

Our study addresses several methodological limitations in past studies. We examined separate categories of prepregnancy obesity (class I versus II/III) and found that associations were limited to women in the class II/III category. We performed a more comprehensive adjustment for potential confounders and causal pathway factors than most past studies and demonstrated that our findings are not explained by many pregnancy and postpartum factors known to be associated with maternal obesity or child development. Finally, we assessed a wide range of child development including behavioral symptoms, developmental delays, disabilities, and special needs services measured by maternal report, health care provider diagnosis, and provision of developmental services. Notably, our results were robust and internally consistent across the 3 neurodevelopmental outcome subtypes.

Ascertainment of neurodevelopmental outcomes is a key concern in studies of prepregnancy risk factors and child

TABLE 3 Likelihood of Moderate/High SDQ Scores, Developmental Diagnoses, and Current Receipt of Special Needs Services at 6 Years of Age by Maternal Prepregnancy BMI, Y6FU Study, 2012

	Crude OR (95% CI)	OR Adjusted for Confounders (95% CI)[a]	OR Adjusted for Confounders and Mediators (95% CI)[b]
SDQ scores[c]			
Emotional symptoms			
Maternal prepregnancy BMI			
Underweight	1.67 (0.67–4.14)	1.42 (0.56–3.62)	1.21 (0.45–3.22)
Normal	Reference	Reference	Reference
Overweight	1.16 (0.70–1.92)	1.21 (0.72–2.03)	1.18 (0.69–2.02)
Obese I	1.36 (0.74–2.48)	1.45 (0.79–2.69)	1.48 (0.77–2.81)
Obese II/III	2.20[d] (1.28–3.78)	2.24[d] (1.27–3.98)	1.94[d] (1.05–3.58)
Conduct problems			
Maternal prepregnancy BMI			
Underweight	0.83 (0.32–2.17)	0.71 (0.27–1.89)	0.68 (0.25–1.84)
Normal	Reference	Reference	Reference
Overweight	1.17 (0.77–1.77)	1.08 (0.71–1.66)	1.06 (0.68–1.65)
Obese I	1.52 (0.94–2.47)	1.47 (0.89–2.42)	1.34 (0.80–2.25)
Obese II/III	1.71[d] (1.05–2.77)	1.47 (0.88–2.45)	1.19 (0.69–2.04)
Hyperactivity			
Maternal prepregnancy BMI			
Underweight	0.57 (0.22–1.47)	0.46 (0.17–1.22)	0.44 (0.16–1.18)
Normal	Reference	Reference	Reference
Overweight	1.05 (0.73–1.52)	1.06 (0.72–1.55)	1.09 (0.73–1.61)
Obese I	1.09 (0.68–1.73)	1.14 (0.71–1.84)	1.13 (0.69–1.85)
Obese II/III	1.32 (0.84–2.08)	1.31 (0.81–2.12)	1.15 (0.69–1.90)
Peer problems			
Maternal prepregnancy BMI			
Underweight	1.20 (0.52–2.77)	1.04 (0.44–2.47)	0.97 (0.40–2.35)
Normal	Reference	Reference	Reference
Overweight	1.09 (0.72–1.65)	1.17 (0.76–1.80)	1.16 (0.75–1.81)
Obese I	0.99 (0.58–1.71)	1.04 (0.60–1.82)	1.01 (0.57–1.78)
Obese II/III	1.90[d] (1.19–3.04)	2.07[d] (1.26–3.40)	1.83[d] (1.09–3.09)
Prosocial behavior			
Maternal prepregnancy BMI			
Underweight	0.60 (0.14–2.56)	0.58 (0.13–2.57)	0.50 (0.11–2.26)
Normal	Reference	Reference	Reference
Overweight	1.20 (0.71–2.05)	1.11 (0.64–1.93)	1.12 (0.63–1.99)
Obese I	0.46 (0.18–1.20)	0.47 (0.18–1.22)	0.47 (0.18–1.26)
Obese II/III	1.35 (0.70–2.62)	1.33 (0.66–2.67)	1.08 (0.51–2.25)
Total SDQ score			
Maternal prepregnancy BMI			
Underweight	0.43 (0.10–1.83)	0.30 (0.07–1.34)	0.27 (0.06–1.21)
Normal	Reference	Reference	Reference
Overweight	0.91 (0.55–1.50)	0.91 (0.54–1.53)	0.90 (0.52–1.54)
Obese I	1.07 (0.59–1.97)	1.09 (0.58–2.04)	1.06 (0.56–2.03)
Obese II/III	2.16[d] (1.29–3.61)	2.17[d] (1.24–3.77)	1.88[d] (1.04–3.39)
Child ever diagnosed with ADD/ADHD[e]			
Maternal prepregnancy BMI			
Underweight	0.96 (0.12–7.54)	0.51 (0.06–4.33)	0.51 (0.06–4.53)
Normal	Reference	Reference	Reference
Overweight	1.83 (0.81–4.12)	2.04 (0.88–4.75)	1.83 (0.76–4.39)
Obese I	1.21 (0.39–3.80)	1.18 (0.36–3.87)	1.03 (0.31–3.48)
Obese II/III	3.62[d] (1.57–8.36)	4.55[d] (1.80–11.46)	3.76[d] (1.41–10.05)
Child ever diagnosed with autism/DD[e]			
Maternal prepregnancy BMI			
Underweight	2.36 (0.50–11.07)	2.34 (0.45–12.19)	2.63 (0.48–14.48)
Normal	Reference	Reference	Reference
Overweight	1.08 (0.39–3.01)	1.08 (0.38–3.08)	1.11 (0.37–3.40)
Obese I	N/A	N/A	N/A
Obese II/III	2.70[d] (1.01–7.21)	3.13[d] (1.10–8.94)	3.21 (0.97–10.64)
Child ever diagnosed with depression or anxiety[e]			
Maternal prepregnancy BMI			
Underweight	1.66 (0.20–13.77)	1.44 (0.16–12.80)	1.37 (0.15–12.79)

TABLE 3 Continued

	Crude OR (95% CI)	OR Adjusted for Confounders (95% CI)[a]	OR Adjusted for Confounders and Mediators (95% CI)[b]
Normal	Reference	Reference	Reference
Overweight	0.77 (0.20–3.00)	0.81 (0.20–3.24)	0.98 (0.24–4.03)
Obese I	0.51 (0.06–4.20)	0.60 (0.07–4.96)	0.73 (0.09–6.32)
Obese II/III	2.73 (0.86–8.73)	3.08 (0.89–10.58)	2.95 (0.78–11.12)
Child ever diagnosed with hearing problems[e]			
Maternal prepregnancy BMI			
Underweight	0.60 (0.08–4.57)	0.51 (0.06–3.99)	0.51 (0.06–4.06)
Normal	Reference	Reference	Reference
Overweight	0.85 (0.38–1.90)	0.89 (0.39–2.02)	0.77 (0.33–1.79)
Obese I	1.75 (0.78–3.95)	1.97 (0.86–4.51)	1.85 (0.78–4.40)
Obese II/III	1.82 (0.81–4.11)	2.00 (0.84–4.75)	1.79 (0.73–4.41)
Current speech or language therapy[f]			
Maternal prepregnancy BMI			
Underweight	1.48 (0.67–3.30)	1.42 (0.63–3.24)	1.38 (0.59–3.18)
Normal	Reference	Reference	Reference
Overweight	1.30 (0.87–1.95)	1.20 (0.79–1.82)	1.16 (0.76–1.78)
Obese I	0.75 (0.41–1.37)	0.70 (0.38–1.29)	0.67 (0.35–1.25)
Obese II/III	2.11[d] (1.32–3.37)	1.93[d] (1.18–3.15)	1.87[d] (1.12–3.15)
Current occupational or therapy for motor skills[f]			
Maternal prepregnancy BMI			
Underweight	1.29 (0.38–4.40)	1.41 (0.40–4.97)	1.38 (0.39–4.97)
Normal	Reference	Reference	Reference
Overweight	0.71 (0.35–1.46)	0.66 (0.32–1.36)	0.62 (0.29–1.31)
Obese I	0.39 (0.12–1.29)	0.35 (0.10–1.19)	0.31 (0.09–1.06)
Obese II/III	1.44 (0.68–3.04)	1.35 (0.62–2.97)	1.11 (0.48–2.55)
Current special help in school projects[f]			
Maternal prepregnancy BMI			
Underweight	0.91 (0.31–2.62)	0.91 (0.31–2.68)	0.88 (0.30–2.63)
Normal	Reference	Reference	Reference
Overweight	0.84 (0.51–1.39)	0.78 (0.46–1.30)	0.71 (0.42–1.20)
Obese I	1.16 (0.64–2.09)	1.09 (0.60–2.00)	0.91 (0.49–1.69)
Obese II/III	1.60 (0.92–2.79)	1.50 (0.84–2.67)	1.24 (0.68–2.27)
Current special services for vision or hearing[f]			
Maternal prepregnancy BMI			
Underweight	2.89 (0.32–26.39)	3.00 (0.31–29.28)	3.38 (0.31–37.33)
Normal	Reference	Reference	Reference
Overweight	1.78 (0.44–7.18)	2.20 (0.52–9.26)	1.94 (0.42–8.91)
Obese I	1.79 (0.33–9.89)	2.23 (0.39–12.65)	1.63 (0.26–10.22)
Obese II/III	2.89 (0.64–13.07)	3.98 (0.79–19.99)	4.09 (0.71–23.45)
Current psychological services[f]			
Maternal prepregnancy BMI			
Underweight	0.91 (0.21–3.96)	0.65 (0.14–3.03)	0.63 (0.14–2.93)
Normal	Reference	Reference	Reference
Overweight	0.99 (0.51–1.94)	0.97 (0.49–1.93)	1.04 (0.51–2.11)
Obese I	0.42 (0.12–1.40)	0.43 (0.13–1.47)	0.44 (0.13–1.51)
Obese II/III	2.25[d] (1.14–4.44)	2.27[d] (1.09–4.73)	2.24[d] (1.03–4.85)
Current support in classroom by assistant[f]			
Maternal prepregnancy BMI			
Underweight	N/A	N/A	N/A
Normal	Reference	Reference	Reference
Overweight	0.88 (0.37–2.09)	0.86 (0.35–2.07)	0.86 (0.35–2.14)
Obese I	0.22 (0.03–1.66)	0.22 (0.03–1.67)	0.18 (0.02–1.44)
Obese II/III	1.45 (0.56–3.76)	1.43 (0.51–4.02)	1.34 (0.44–4.07)
Current other special services[f]			
Maternal prepregnancy BMI			
Underweight	N/A	N/A	N/A
Normal	Reference	Reference	Reference
Overweight	0.59 (0.16–2.19)	0.58 (0.15–2.21)	0.66 (0.17–2.62)
Obese I	0.79 (0.76–3.70)	0.81 (0.17–3.92)	1.21 (0.23–6.37)
Obese II/III	1.71 (0.52–5.63)	1.95 (0.56–6.77)	2.48 (0.65–9.45)

TABLE 3 Continued

	Crude OR (95% CI)	OR Adjusted for Confounders (95% CI)[a]	OR Adjusted for Confounders and Mediators (95% CI)[b]
Currently received any of these[f]			
Maternal prepregnancy BMI			
Underweight	1.37 (0.73–2.59)	1.26 (0.65–2.42)	1.21 (0.62–2.37)
Normal	Reference	Reference	Reference
Overweight	0.95 (0.69–1.32)	0.89 (0.64–1.24)	0.86 (0.61–1.21)
Obese I	0.86 (0.56–1.32)	0.82 (0.53–1.27)	0.77 (0.49–1.20)
Obese II/III	2.07[d] (1.42–3.03)	1.99[d] (1.33–2.97)	1.88[d] (1.23–2.85)

CI, confidence interval.

[a] Adjusted for maternal age, maternal race or ethnicity, marital status, mother's education, poverty-to-income ratio, smoking during third trimester, parity, child's gender, child's current BMI, and child's enrichment. Black, Hispanic, Asian/Pacific Islander, and other categories were combined as 1 group and compared with white for maternal race or ethnicity. Child's enrichment was dichotomized as having received any (read aloud or special lessons) and having received none.

[b] Adjusted for aforementioned confounders plus birth weight, pregnancy weight gain, gestational diabetes, breastfeeding, and postpartum depression. Each category of composite breastfeeding was compared with those who never breastfed.

[c] These estimates are based on 1241 mother–child pairs with complete information on covariates to examine child's SDQ scores.

[d] CI does not include 1.0.

[e] These estimates are based on 1311 mother–child pairs with complete information on covariates to examine child's developmental diagnoses.

[f] These estimates are based on 1253 mother–child pairs with complete information on covariates to examine child's current receipt of special needs services.

neurodevelopment because of the lack of specific diagnostic biomarkers. Outcome measures rely on parent or provider observations or child's responses on a standardized test. Tests of cognitive skills or achievement such as reading, math ability, and achievement tests are probably highly influenced by the child's early enrichment opportunities and other family sociodemographic factors[33]; therefore, using such tests to specifically assess prenatal or preconceptional influences on child neurodevelopment presents inherent difficulties. Despite control of sociodemographic confounders, the possibility of unmeasured confounding remains. Measures relying on specific diagnoses or placement in developmental services are helpful because they require some threshold level of developmental deficit that meets diagnostic criteria or to a lesser extent, service receipt criteria. However, developmental diagnoses and special education placements are often subject to parents' access and ability to navigate complex health and educational systems and cultural or individual factors that might influence parents' recognition of developmental delays and treatment-seeking behavior.[34,35] Because there is no biologic measure to serve as the gold standard for defining neurodevelopmental impact, using multiple measures with differing strengths and limitations allowed us to assess the internal validity of our findings.

Our assessment of SDQ scores was an important supplement to our measures based on diagnoses and service receipt. In the SDQ, parents are simply asked about individual behavioral attributes such as "considerate of other people's feelings" or "is easily distracted, concentration wanders." Thus, responses are probably less driven by parents' concerns about specific diagnoses. SDQ outcomes are also not affected by access to or use of services.

Only 1 other study has conducted a comprehensive assessment by using multiple measures of neurodevelopmental outcome. Hinkle et al[14] reported associations between prepregnancy maternal class II/III obesity and both past diagnoses of learning or behavioral developmental disabilities and lower scores on standardized reading tests at age 5. Although the specific outcomes were different, the findings are generally consistent with those reported here.

Additional studies are needed to elucidate the underlying mechanisms of these associations. It has been hypothesized that increased systemic inflammation associated with maternal obesity alters fetal brain development and makes the brain more vulnerable to other environmental factors, which may lead to the increased risk for cognitive disabilities.[8,36] Additionally, prepregnancy obesity increases the risk of numerous pregnancy complications.[6]

We did not observe an independent association between any outcome and excessive pregnancy weight gain. Although this finding is consistent with several studies,[16,17,37] 2 recent studies reported positive associations. Rodriguez et al[19] found that excessive pregnancy weight gain among obese women increased children's ADHD risk. Bilder et al[38] reported an association between autism spectrum disorder and high pregnancy weight gain, independent of prepregnancy BMI; however, the latter study examined prepregnancy BMI as a continuous variable and did not assess interactions between prepregnancy BMI and weight gain.

Despite its strengths, this study also has potential limitations. Although our sample includes a large cohort followed longitudinally, it was not

nationally representative; mother–child pairs in this study were less likely to be nonwhite or low SES than mother–child pairs in the general US birth cohort from the same time period.[24] Nonetheless, our study design was internally valid, and the associations were adjusted for numerous sociodemographic differences. Moreover, we conducted a thorough stratified analysis before developing regression models and did not observe differential effects in any of the sociodemographic subgroup strata (data not shown). Developmental diagnoses were based on maternal report and not verified clinically. However, previous studies suggest that select conditions such as autism and behavioral disorders are reliably reported by parents.[39,40] Maternal report of behavioral attributes might vary according to maternal characteristics and thresholds for identifying a particular behavior as a problem; although we could not control for such factors, such variability was unlikely to be associated with prepregnancy BMI. We were unable to separately examine autism/DD diagnoses; however, the strong association with prepregnancy BMI we observed indicates that the association might be stronger if the more specific diagnosis of autism were examined separately. Maternal BMI estimates were not directly measured. Validation studies indicate that women tend to underreport their weight, particularly overweight or obese women.[41,42] However, it is unlikely that height and weight reporting differed according to child outcome measures or that reporting of developmental diagnoses differed according to prepregnancy BMI. Thus, the impact of using self-reported measures for weight and height would probably be a bias toward the null hypothesis; the associations reported here might therefore be conservative. Finally, we lacked information on child's medication use; therefore, we cannot determine whether the disparity in our findings of a strong association with past ADHD diagnosis yet no association with current hyperactivity symptoms resulted in part from current use of ADHD medications.

CONCLUSIONS

We found that high prepregnancy BMI was associated with neurodevelopmental outcomes among 6-year-old children. Children of severely obese mothers had significantly increased odds of having emotional symptoms, peer problems, total psychosocial difficulties, previous developmental diagnoses, and receipt of special needs services compared with children of normal weight mothers. This study adds to the limited body of literature documenting that prepregnancy obesity may have long-term neurologic effects on children. Given the high proportion of obesity among women of reproductive age and the recent increase in developmental disabilities in children, future studies should focus on evaluating maternal obesity as a potential predictor of developmental delays in children. Finally, these findings support previous recommendations of focusing on preconception health to help women achieve and maintain a healthy weight and lifestyle before pregnancy.

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