

The impact of maternal prenatal smoking on the development of childhood overweight in school-aged children

L. Wang¹, H. M. Mamudu² and T. Wu^{1,3}

¹Department of Biostatistics and Epidemiology, College of Public Health, East Tennessee State University, Johnson City, TN, USA;

²Department of Health Services Management and Policy, College of Public Health, East Tennessee State University, Johnson City, TN, USA; ³Department of Family Medicine, James H. Quillen College of Medicine, East Tennessee State University, Johnson City, TN, USA

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What is already known about this subject

- Maternal smoking during pregnancy likely increase the risk of childhood overweight.
- Childhood overweight is influenced by socioeconomic characteristics of mothers.
- Characteristics of child at birth determine the likelihood of overweight.

What this study adds

- Children of mothers who smoked 1 year before birth (including pregnancy) were likely to be overweight during school ages than those of mothers who never smoked.
- Confirmation that socioeconomic characteristics of mothers influence the likelihood of childhood overweight during school age.
- Smoking cessation should be targeted at mothers 1 year before birth to improve their health status and that of offspring.

Summary

Objectives: To examine associations between maternal smoking and overweight among school-aged children and also identify mothers and offspring characteristics that affect children's weight.

Methods: We used data from the National Institute of Child Health and Human Development (NICHD) Study of Early Child Care and Youth Development (SECCY). Childhood overweight was defined as having Body Mass Index (BMI) of 85th percentile or above. Smoking patterns among mothers were assessed by questioning smoking behaviour 1 year before birth of the target child: never or ever smoking. Standardized procedures were used to measure height and weight. Descriptive statistics and generalized estimating equations (GEE) were used for the analysis.

Results: Descriptive results showed that children of mothers who smoked anytime within 1 year before birth were more likely to be overweight and have higher BMI percentile averages. GEE results showed that children of mothers who were ever smokers 1 year before birth were more likely to be overweight (OR = 1.39, 95% CI: 1.01, 1.94) and have higher BMI percentile averages ($\beta = 4.46$, $P = 0.036$) from grades 1 through 6 than those of mothers who were never smokers. Additionally, the level of mother's education and birth weight were significantly associated with childhood overweight.

Conclusions: Confirmed relationships between maternal smoking and overweight among school-aged children have important implications for public health policy because this evidence can be used to enhance smoking cessation 1 year before birth to improve the health status of mothers and offspring.

Keywords: Childhood overweight, longitudinal study, maternal prenatal smoking, risk factor.

Address for correspondence: Dr L Wang, Department of Biostatistics and Epidemiology, East Tennessee State University, PO Box 70259, Johnson City, TN 37614, USA. E-mail: wangl2@etsu.edu

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Introduction

The prevalence of overweight and obesity has been increasing worldwide and has emerged as a global public health issue (1), thus leading to efforts to identify the root causes of the problem. Data from the National Health and Nutrition Examination Survey (NHANES) in the United States indicate that the prevalence of adult overweight and obesity was 34.4% in 2008 (2) and 35.7% in 2010 (3). The data also show that the prevalence of overweight and obesity among school-aged children between 6 and 11 years of age in 2008 was 35.5% and 19.6%, respectively (4). The rate of prevalence of obesity in children between 2 and 19 years of age (16.9%) remained steady between 2008 and 2010 despite efforts to reduce it (5). For this reason, the obesity rate 31% in 2010 in the United States is expected to reach over 42% by 2030 if drastic efforts are not taken to identify the sources and interventions for it (6).

Overweight and obesity among children in the United States has increased dramatically over the past three decades to reach epidemic proportions. Obesity in children aged two years and older has at least doubled in the last 25 years and tripled in the past 30 years (7). The dramatic increase in childhood overweight and obesity has resulted in 'childhood' diseases that were once thought of as primarily 'adult' diseases, such as type II diabetes (8), hypertension, hyperlipidemia, high cholesterol levels and abnormal glucose tolerance (9,10). Additionally, overweight children and adolescents often have psychosocial problems, including compromised health related to quality of physical, emotional and social well-being (11–14). Moreover, obese children are least desired to be friended by peers (15) and more likely to be bullied (16), which leads to a poor self-image that persists into adulthood (17). Thus, overweight or obesity is not only a health problem but also a social problem. However, the age at which overweight and obesity starts is not obvious, thus demanding investigation into the sources of the problem for early intervention.

Previous studies have identified socioeconomic, demographic and environmental determinants of overweight and obesity (1,18). Increasing studies on populations in places, such as Japan (19), Europe (20), Canada (21) and the United States (22) have turned to the lifestyle of mothers that impact foetal programming and lead to overweight or obesity in childhood (and adulthood). A key marker for childhood (and adult) obesity is maternal smoking (1,23–26). This relationship is due to a number of possible reasons, including intrauterine malnutrition (27) and

toxic effects of cigarette smoke (28) that may result in elevated concentration of cortisol in the cord blood (29). All these metabolic mechanisms may have an adverse impact on foetal programming and could negatively impact the weight of offspring (30). Thus, maternal smoking does not only lead to low birth weight (31), but it is also related to catching up growth in childhood that leads to overweight and obesity (32,33). Despite this increasing evidence, studies about the effects of whether or not the mother had ever smoked within the entire year before birth on the weight status of offspring are sparse. Therefore, this study analyzes effects of mothers' smoking status within 1 year before birth on overweight of school-aged children in the United States using longitudinal cohort data. Simultaneously, the study identifies maternal and offspring characteristics that impact the weight of offspring during school ages. While the study helps to identify mothers' behaviours that impact the weight of offspring, it provides useful information for understanding foetal programming and suggests that the year before the birth may be an important period for intervention to prevent childhood overweight. This study may contribute to targeting maternal smoking behaviour before birth and its adverse outcome as an integral part of efforts to prevent the obesity rate in the country from reaching 42% by 2030 (6).

Materials and methods

Data source and participants

Since 1991, the National Institute of Child Health and Human Development (NICHD) Study of Early Child Care and Youth Development (SECCYD) has been conducted at 10 research hospitals across the United States. Detailed recruitment and selection procedures have been published in a previous study (34) and <http://www.nichd.nih.gov/research/supported/seccyd/overview.cfm>.

In brief, of a total of 8986 mothers that gave birth in the research hospitals during sampling periods in 1991, 5416 (60%) agreed to be telephoned in 2 weeks. The exclusion criteria for mother–baby dyads included mothers younger than 18 years, those that did not speak English, did not agree with the 2-week phone call, had history of substance abuse and the baby had medical complications. Additional exclusion criteria were neighbourhoods unsafe for teams of researchers to visit, families living in the same location for less than 1 year and families living too far away from the research site (more than 1 h drive) (35). These criteria were used to screen out very low

birth weight, premature or sick infants. Guided by the mothers' plans to return to work or school within a year after delivery (in the ratio of 3:1:1 – full-time workers: part-time workers: non-workers), the conditionally random sampling, a sketch-based sampling technique, that includes the advantages of both sketching and random sampling (36) was designed to provide sufficient data to allow for some statistical adjustments to reflect characteristics of the base sample. The sampling technique was used to ensure that single-parent, low-maternal education and minority distributional targets were met while continuing to select cases at random (37). Data from the Hospital Recruitment and Gestational Age forms were entered into a database at the Data Coordinating Center (DCC). Conditional random calling lists were then generated by the DCC. A sample of 3015 (56%) mothers was selected from the 5416 mothers who agreed to be telephoned in 2 weeks. Of these 3015 mothers in the sample, 1526 were available for the interview at 1 month age of the child. Of the 1526 mothers, 1364 (89.4%) finished the interview and became study participants in 1991. At 24 months interview after birth, two people, a visit coordinator/examiner and camera operator, conducted the laboratory visit. The visit coordinator/examiner was responsible for greeting the family, explaining each procedure to the mother and administering the procedures; and the operator served as operator of the video camera. Mothers were asked to recall their prenatal smoking habits. In this study, we restricted children with measure of body mass index (BMI) at one or more time points (grades 1, 3 or 6) and those whose mothers were not missing information on their smoking behaviours within 1 year before birth to get our analytic sample (1041). Phase I (1991–1994), phase II (1995–2000) and phase III (2000–2005) of the SECCYD data were used in the analysis. The attrition rate for the study sample was 20.1%.

The Institutional Review Board of East Tennessee State University approved this study.

Variables

Childhood overweight status

The key outcome variable was BMI percentile, which was calculated according to the U.S. Centers for Disease Control and Prevention's (CDC) age and gender-specific growth charts (38). The CDC's nomenclature defined overweight for a child as a BMI (defined as weight in kilograms divided by squared height in meters) equal to or greater than the 85th percentile. As such, the outcome variable in this study, childhood overweight status, was measured

as a dichotomized variable (BMI $\leq$ 85th percentile or normal weight, BMI $\geq$ 85th percentile or overweight). Standardized procedures were used to measure height and weight during the interviews by NICHD SECCY staff. Height was measured with children standing without shoes, feet together and their backs against a calibrated 7-foot measuring stick. Weight was measured using a physician's 2-beam scale. Scales were calibrated monthly using certified calibration weights. Weight was measured with children in minimal clothing and recorded twice, each time to the nearest 0.25 pound (0.1 kg). This NICHD SECCY study followed the same children from birth through grades 1 (2000), 3 (2002) and 6 (2005). We used data on BMI values from when the children were in these grades as outcome variables.

Maternal prenatal smoking

Mother's smoking status within 1 year before the birth (1990) of the target child were assessed retrospectively with 'The year before my child was born' question (39), which consisted of two items measuring mother's smoking behaviour shortly before and during pregnancy. Because of the small sample size (1041) and study purposes, mother's smoking status was divided into two categories, never smoking and ever smoking within 1 year before the birth of target child.

Covariates

The main covariates, which encompassed maternal characteristics, were collected at the 1 month of child age interview. These covariates include maternal age, education (bachelor's degree or above, less than a bachelor's degree), living status (living single, not living single), poverty (above poverty line, i.e. \$6932 for a single person and \$8797 for a family of two in 1991 (40), at or below poverty line) and breastfeeding status (breastfeeding, not breastfeeding). Other covariates involved offspring characteristics, such as sex, ethnicity and birth weight. Child sex and ethnicity were recorded at 1 month after birth. The sample sizes for individual ethnic minority groups were not large enough to allow separate subgroups' analyses, thus, this study categorized ethnicity into Whites, Blacks, or Others. Child's birth weight in grams was obtained from medical chart as a continuous variable.

Statistical analysis

We analyzed these data using univariate (frequencies and percentages), bivariate (chi-square and

t-test) and multivariate (Generalized Estimating Equations [GEE]) statistics. In the bivariate analysis, while the chi-square test was used to determine whether there is any association between categorical variables, the student *t*-test was used to determine whether there is any difference in the means of continuous variables between two groups. Using chi-square test and student *t*-test, we compared maternal and child's characteristics in our analytic sample ($n = 1041$) with those excluded due to incomplete data on childhood overweight in school ages and maternal smoking status within 1 year before the birth ($n = 323$). We then compared maternal and child's characteristics with dichotomous maternal smoking status (never smoker vs. ever smoker) within 1 year before the birth in our analytic sample. Additionally, to describe the distribution of overweight status in the two groups at three measures, we examined the distribution of mean BMI percentiles and proportions of overweight children by maternal smoking status (never smoker vs. ever smoker) within 1 year before the birth at grades 1, 3 and 6, respectively. Finally, we used GEE for the multivariate analysis because, in comparison with traditional regression analysis at one time point (cross-sectional), it considers all repeated measurements of the health outcomes by accounting for their dependency (41,42). More specifically, classical analyses such as regression do not consider the pattern across time, and are not adequate to address changes in mean response over time. In this longitudinal study, the independence assumption was not satisfied because children were measured at multiple follow-up time points. For this reason, the correlation of data within each child could be close and should not be ignored. The GEE was used to address this issue through the use of 'working correlation' structure to account for the within-subject correlation of response on dependent variables of different distributions (41). In other words, GEE models were used to account for within-subject correlation across three time points (grades 1, 3 and 6) of measurements for categorical (childhood overweight status) and continuous (BMI percentile) variables. While 74.4 % of children had BMI measurements at all three time points, 89.4 % had BMI measurements at least at two time points. In this longitudinal study, the missing BMI percentiles were assumed to be missing at random, which was regularly used to address missing data in longitudinal data analysis (43). First-order auto-regression [AR(1)] was used as the working correlation matrix for performing the GEE to account for correlations among repeated measurements in the BMI. Statistical sig-

nificance was defined as having a *P*-value ≤ 0.05 for two-tailed testing. All data analyses were performed using PASW version 18.0 statistical software (IBM SPSS, Chicago, Illinois).

Results

Of the 1041 mothers, 812 (78%) were never smokers and 229 (22%) were ever smokers. The characteristics of the study sample were shown in Table 1. The mean age of the mothers was about 29 years, and the majority of them had less than a bachelor's degree (60.6%), were not living single (87.2%), were above the poverty line (82.1%; \$6932 for a single and \$8865 for a family of two in 1991 (37)) and were breastfeeding (62%). With respect to the offspring, half of them were males (50.4%), more often white (81.5%) and had a mean birth weight of 3503.2 grams. Compared with mothers in the analytic sample ($n = 1041$), mothers in the excluded sample due to incomplete data ($n = 323$) were more likely to smoke within 1 year before birth ($P = 0.002$), have younger ages ($P < 0.0001$), have lower education ($P < 0.0001$), living single ($P = 0.001$), at or below poverty line ($P < 0.0001$) and breastfeed ($P < 0.0001$). With respect to child's sex, ethnicity and birth weight, there were no difference between analytic and excluded samples.

Table 2 shows that compared to never smokers, ever smokers were more likely to be seen in mothers who had younger age ($P < 0.0001$), were less educated than bachelor's degree ($P < 0.0001$), living single ($P < 0.0001$), at or below poverty level ($P = 0.001$) and not breastfeeding ($P < 0.0001$).

The distribution of mean BMI percentile and proportions of overweight children described by maternal smoking status within 1 year before the birth and at the time of assessment were reported in Table 3. Generally, the proportion of childhood overweight (25.0%, 31.2% and 33.7% at grades 1, 3 and 6, respectively) and mean BMI percentile increased with increases in the level of school grade, suggesting a positive relationship between grade level and weight. Additionally, children of mothers who were ever smokers were more likely to be overweight than those of mothers who did not smoke (30.3% vs. 23.5%, 37.1% vs. 29.6%, 41.4% vs. 31.6% at grades 1, 3 and 6, respectively), and on average, have higher BMI percentiles.

GEE results after adjusting for the covariates were reported in Table 4, which showed that maternal smoking within 1 year before birth was significantly associated with childhood overweight. That is, children of mothers who were ever smokers were more

Table 1 Comparison of maternal and child characteristics of the study sample in the analytic sample with those not included due to incomplete data

	Analytic sample*	Not in analytic sample†	P
Overall [n (%)]	1041 (76.3)	323 (23.7)	
Maternal characteristics			
<i>Smoking status 1 year before birth</i> ‡			0.002
Ever smoker	229 (22.0)	50 (33.8)	
Never smoker	812 (78.0)	98 (66.2)	
<i>Age</i> §			
Mean age at delivery, years (SD)	28.6 (5.5)	26.5 (5.7)	<0.0001
<i>Education</i> ‡			
Bachelor's degree or above (%)	410 (39.4)	72 (22.4)	
Less than a bachelor's degree (%)	631 (60.6)	250 (77.6)	
<i>Living status</i> ‡			0.001
Living single (%)	133 (12.8)	65 (20.2)	
Not living single (%)	906 (87.2)	257 (79.8)	
<i>Poverty level</i> ‡			<0.0001
At or below poverty line (%)	176 (17.9)	97 (33.2)	
Above poverty line (%)	805 (82.1)	195 (66.8)	
<i>Breastfeeding status</i> ‡			<0.0001
Not breastfeeding (%)	396 (38.0)	191 (59.1)	
Breastfeeding (%)	645 (62.0)	132 (40.9)	
Offspring characteristics			
<i>Sex</i> ‡			0.096
Male (%)	525 (50.4)	180 (55.7)	
Female (%)	516 (49.6)	143 (44.3)	
<i>Ethnicity</i> ‡			0.099
Whites (%)	848 (81.5)	249 (77.1)	
Blacks (%)	123 (11.8)	53 (16.4)	
Others (%)	70 (6.7)	21 (6.5)	
<i>Birth weight</i> §			
Mean birth weight, grams (SD)	3503.2 (511.4)	3445.5 (489.0)	0.332

*Subjected included in analytic sample ($n = 1041$). Of these, 1 was missing data on living single status, 60 were missing data on maternal poverty level.

†Subjects excluded due to incomplete data on childhood overweight in school ages and children whose mothers were missing information on their smoking behaviours within 1 year before birth ($n = 323$). Of these, 2 were missing data on living single status, 31 were missing data on maternal poverty level, and 1 was missing data on maternal education.

‡Chi-square (χ^2) test was used for P -value.

§T-test was used for P -value.

likely to be overweight (OR = 1.39, 95% CI: 1.01, 1.94) and have higher BMI percentile ($\beta = 4.46$, $P = 0.036$) from grades 1 through 6 than children of mothers who were never smokers during the year before the birth. Additionally, two covariates, maternal education and birth weight of offspring were significantly associated with childhood overweight. In this respect, children of mothers with less than a bachelor degree were more likely to be overweight (OR = 1.41, 95% CI: 1.05, 1.91) and children with higher birth weight (in kilograms) were also likely to be overweight (OR = 1.99, 95% CI: 1.52, 2.61). All other covariates were not significant.

Discussion

Tobacco use during pregnancy is a major public health issue due to the negative effects on both the mother and offspring (4). While maternal prenatal smoking is known to be linked with negative health effects on offspring, such as low birth weight (31), evidence of its effects on the weight of offspring is still sparse. Our study investigated effects of whether the mother had ever smoked within 1 year before the birth of the target child on the weight of the child during school ages. Consistent with the existing literature that linked smoking during pregnancy with

	Never smoker	Ever smoker	P
Overall [n (%)]	812 (78)	229 (22)	
Maternal characteristics			
Age [†]			<0.0001
Mean age at delivery, years (SD)	29.1 (5.4)	26.8 (5.6)	
Education [†]			<0.0001
Bachelor's degree or above (%)	372 (45.8)	38 (16.6)	
Less than bachelor's degree (%)	440 (50.2)	191 (83.4)	
Living status [†]			<0.0001
Living single (%)	84 (10.4)	49 (21.4)	
Not living single (%)	726 (89.6)	180 (78.6)	
Poverty level [†]			0.001
At or below poverty line (%)	122 (15.8)	54 (26.1)	
Above poverty line (%)	652 (84.2)	153 (73.9)	
Breastfeeding status [†]			<0.0001
Not breastfeeding (%)	282 (34.7)	114 (49.8)	
Breastfeeding (%)	530 (65.3)	115 (50.2)	
Offspring characteristics			
Sex [†]			0.60
Male (%)	406 (50.0)	119 (52.0)	
Female (%)	406 (50.0)	110 (48.0)	
Ethnicity [†]			0.28
Whites (%)	662 (81.5)	186 (81.2)	
Blacks (%)	100 (12.3)	23 (10.0)	
Others (%)	50 (6.2)	20 (8.7)	
Birth weight [†]			0.01
Mean birth weight, grams (SD)	3524.9 (516.2)	3426.3 (487.4)	

Note: Number of missing observations: single = 2; poverty = 60.

*Mothers were interviewed at children 24 months after birth for their smoking status within 1 year before the birth.

[†]t test was used, the numbers indicate mean $\pm$ standard deviation (SD).

[‡]chi-square (χ^2) test was used, the numbers indicate percentage values.

Table 2 Characteristics of the analytic sample by maternal smoking status* within 1 year before the birth (n = 1041)

Table 3 Distribution of mean BMI-P* and proportions of overweight children by maternal prenatal smoking status[†] and time of assessment (n = 1041)

Time	Never smoker			Ever smoker			Total		
	n	BMI_P*	Overweight [‡] (%)	n	BMI_P*	Overweight [‡] (%)	n	BMI_P*	Overweight [‡] (%)
Grade 1	756	61.9	23.5	208	65.6	30.3	964	62.7	25.0
Grade 3	706	63.8	29.6	197	67.8	37.1	903	64.7	31.2
Grade 6	693	62.3	31.6	186	69.7	41.4	879	63.9	33.7

*A standardized protocol to measure child's weight and height was used at all three times (grades 1, 3, 6). Body mass index (BMI) was calculated by [BMI = weight (kg)/height (m)²].

[†]Mothers were interviewed at children 24 months after birth for their smoking status within 1 year before the birth.

[‡]Overweight was defined as a BMI-for-age above the 85th percentile of the Centers for Disease Control and Prevention sex-specific BMI-for-age growth charts (35).

BMI-P, body mass index percentile.

childhood overweight and obesity (1,23), our study discovered a higher prevalence of overweight among children of mothers who ever smoked within 1 year before the birth. After adjusting for covariates, GEE results showed that maternal smoking within 1 year before birth significantly increased the likelihood of overweight by 1.39 times, suggesting the need for

smoking cessation programmes to encourage mothers to abstain from smoking at least a year before the birth of the target child.

Although most of the covariates (maternal and offspring characteristics) in our study were not significantly associated with childhood overweight, the two significant ones, the level of education and birth

Table 4 Longitudinal analysis of mean BMI-P and overweight status from grades 1 through 6 using GEE* (*n* = 1041)

	BMI-P [†]			Overweight status [‡]		
	β	SE	<i>P</i>	OR	95% CI	<i>P</i>
<i>Maternal smoking status</i> ^d						
Never smoker (reference)						
Ever smoker	4.46	2.12	0.036	1.39	1.01–1.94	0.047
<i>Maternal characteristics</i>						
<i>Age</i>						
Mean age at delivery, years	−0.22	0.18	0.235	0.98	0.96–1.01	0.189
<i>Education</i>						
Bachelor's degree or above (reference)						
Less than bachelor's degree	2.25	1.95	0.249	1.41	1.05–1.91	0.025
<i>Living status</i>						
Not living single (reference)						
Living single	1.33	3.46	0.701	0.90	0.53–1.54	0.710
<i>Poverty level</i>						
Above poverty line (reference)						
At or below poverty line	1.88	2.72	0.490	0.93	0.62–1.39	0.72
<i>Breastfeeding status</i>						
Not breastfeeding (reference)						
Breastfeeding	−3.10	1.85	0.093	0.78	0.59–1.04	0.087
<i>Offspring characteristics</i>						
<i>Sex</i>						
Females (reference)						
Males	−0.41	1.66	0.805	1.06	0.82–1.37	0.672
<i>Ethnicity</i>						
Whites (reference)						
Blacks	5.63	3.02	0.062	1.48	0.94–2.32	0.087
Others	0.08	3.72	0.983	1.11	0.67–1.83	0.699
<i>Birth weight (kg)</i>	11.35	1.64	<0.0001	1.99	1.52–2.61	<0.0001

*Analysis of the GEE parameter estimates was based on the use of first order auto-regressive working correlation [AR(1)] structure, with BMI_P as continuous outcome and overweight as dichotomous outcome, respectively.

[†]A standardized protocol to measure child's weight and height was used at all 3 times (grades 1, 3, 6). BMI was calculated by [BMI = weight (kg)/height (m)²].

[‡]Overweight was defined as a BMI-for-age above the 85th percentile of the Centers for Disease Control and Prevention sex-specific BMI-for-age growth charts (35).

^dMothers were interviewed at children 24 months after birth for their smoking status within 1 year before the birth.

BMI_P, body mass index percentile; CI, confidence interval; GEE, generalized estimating equations; OR, odds ratio; SE, standard error.

weight of offspring, need attention. While the evidence linking socioeconomic status of mother and overweight or obesity of children is still not obvious (21,44), it was discovered in our study that a mother not having a bachelor degree significantly increases the likelihood of childhood overweight by 1.41 times. This finding suggests that education, being a driving determinant of socioeconomic status, may be a predictor for increased risk of overweight among offspring, especially as mothers with lower socioeconomic status tend to smoke more. On the issue of birth weight, our finding is consistent with the extant literature that higher birth weight is associated with overweight and obesity in childhood (45). This result

suggests the importance of attending to nutritional needs of children born with higher BMIs. Lastly, results on breastfeeding are worthy of consideration as the evidence of its effects on childhood overweight and obesity is not conclusive (46,47). The results of our study suggest that breastfeeding is probably a protective practice for childhood overweight.

In general, the findings in our study are consistent with previous epidemiological studies on the effects of maternal prenatal smoking on the overweight status of children (21) and our contribution to this literature pertains to the effect of mothers smoking within 1 year before the birth of the target child. Because our study assessed maternal smoking

status for the entire year before the birth, including a few months before pregnancy and the period of pregnancy, possible explanations for the association with negative effects on the weight of offspring can be derived from the extant literature. First, because tobacco is an addictive product (31), mothers who smoked a few months before pregnancy will likely continue to smoke through pregnancy. In other words, there is the possibility that pregnancy will not be deterrence from smoking for mothers who smoked a few months before pregnancy as tobacco is an addictive product. Even if the mothers quit smoking during pregnancy, the potential of recidivism is high, and they may revert back to smoking. Second, hypothalamic dysfunction and abnormal fat cells that result from smoking could explain the positive association between maternal prenatal smoking and overweight and obesity of offspring (48). Previous studies discovered that maternal prenatal smoking increased nicotine levels, which resulted in their maternal starvation (49). Animal studies suggest that maternal starvation is associated with obesity in offspring (50,51) and that it might be caused by altered hypothalamic regulatory mechanisms of energy intake and expenditure (52). Third, the catch-up thesis suggests that low birth weight due to maternal prenatal smoking is associated with a rapid catch-up growth phase in children from birth to grade 6, which leads to overweight and obesity (32,33,53). Simultaneously, some studies have shown that higher birth weight is a predictor for increased risk of childhood obesity (54,55). Fourth, children of smokers tend to be physically inactive, i.e. engage in less than 60 min of physical activity per day (56) and have an inadequate healthy diet, i.e. insufficient fat intake of 25% to 35% kcal, carbohydrate intake of 45% to 65% and protein intakes of 10% to 30% kcal (57). These lifestyle issues lead to overweight or obesity (58–60). Taking everything into consideration, both foetal growth and weight gain in early infancy are directly associated with weight in later life (1,61). This means that maternal prenatal smoking has long-term negative effects on offspring, demanding strategic tobacco cessation programmes for women at least 1 year before the birth.

This study is limited by the fact that there is lack of data for determining the influence of genetic factors, which are determinants of the overweight (62) and show important roles of maternal pregravid obesity, paternal and maternal BMI (63,64), parental weight status (65), maternal weight gain during pregnancy (66) and change in parental weight after birth (24,65) in the development of overweight children. Moreover, the dietary intake of children was not assessed, but

previous studies suggest it is a predictor of childhood obesity (67). Further, although environmental factors, including screening time (TV viewing and computer use) (68) play role in the likelihood of overweight and obesity (69), we did not have the data for this analysis. Thus, residual confounding remains possible due to exclusion of some predictors that may partly explain the observed associations. The study is also limited by the nature of participants involved in the NICHD SECCY data. First, the participants were volunteers, which is subject to self-selection bias. Second, social desirability, a tendency to express favourite answers, may compromise the validity of the self-reported questionnaire of maternal smoking habit recall. Third, some selection bias may have occurred due to incomplete data caused by lost to follow-up and missing data. In our analytic sample (1041), mothers were less likely to smoke than excluded mothers (323), which imply that we may be underestimating the association between maternal smoking and the risk of overweight of offspring. Fourth, maternal education was assumed to be the same as at the 1 month interview, although it could have changed in the course of the study. Despite these drawbacks, the study used longitudinal-cohort data to provide epidemiological insight into how smoking within 1 year before the birth has long-term negative implications for the weight of children and could help in finding interventions to prevent the obesity rate from reaching 42% of the U.S. adult population by 2030 (6).

Conclusions

The confirmed relationship between overweight and maternal prenatal smoking in school-aged children has important implications for public health policy and health status of individual mothers and offspring. The integration of findings of this study in tobacco use prevention programmes within 1 year before the birth of target child could increase the rate of cessation, which will help to improve the health status of offspring. Thus, our study suggests that to reduce childhood overweight and obesity, smoking cessation should start before pregnancy.

Conflicts of interest statement

The authors have none to declare.

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