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Childhood obesity is associated with maternal smoking in pregnancy

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Abstract Overweight and obesity are major public health issues. Childhood obesity often persists throughout adulthood. Recently a higher prevalence of obesity in adults whose mothers smoked during pregnancy was reported. The aim of this study was to assess whether this association is also detectable in pre-school children in a different setting and to identify the critical period for intrauterine exposure to inhaled smoke products in pregnancy. We analysed questionnaire data on early feeding and lifestyle factors of 8,765 German children aged 5.00 to 6.99 years. Obesity was defined as a body mass index >97th percentile. The prevalence estimates for obesity were: mother never smoked 2.8% (95% CI 2.4%–3.2%), smoked after pregnancy only 1.6% (95%CI 0.4%–4.1%), smoked throughout pregnancy 6.2% (95% CI 4.5%–8.3%), smoked before pregnancy, but not throughout 4.5% (95%CI 3.6%–5.7%). These associations could not be explained by confounding due to a number of constitutional, sociodemographic and lifestyle factors. The unadjusted/adjusted odds ratios were: smoked during pregnancy: 2.32 (95% CI 1.63%–3.30%)/1.92 (95% CI 1.29%–2.86%); smoked before, but not throughout pregnancy: 1.67 (95%CI 1.26%–2.22%)/1.74 (95%CI 1.29%–2.34%). *Conclusion*: the association of maternal smoking in pregnancy and obesity was also detectable in children at school entry. Since smoking after pregnancy was not associated with childhood obesity, intrauterine exposure rather than family lifestyle factors associated with smoking appears to be instrumental. There appears to be a role for early intrauterine exposure.

Keywords Barker's hypothesis · Body mass index · Epidemiology · Germany · Primary prevention

Abbreviations *BMI* body mass index · *CI* confidence interval · *OR* odds ratio

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Introduction

In industrialised countries, overweight and obesity are the most common nutritional disorders, showing an increasing prevalence [10]. Overweight children have a high risk for being overweight in adulthood [1, 4]. Since therapeutic interventions for obesity in children are costly and have far from satisfactory results [3], prevention is a major challenge. Prevention requires a better understanding of the causes of childhood overweight and obesity.

Recently Montgomery and Ekbom [9] reported a higher prevalence of obesity in 11,359 British adults aged 33 years from the National Child and Development Study (NCDS) whose mothers had smoked during pregnancy. Non-smoking mothers were defined as all those who did not smoke after the 4th month of pregnancy. We analysed cross-sectional data from the 1997 Bavarian school entry health examination to assess whether this association is also detectable in children at school entry and in children of mothers who stopped smoking during pregnancy.

Subjects and methods

Study population and data sources

In two rural Bavarian regions (Oberpfalz and Niederbayern), 13,345 children were seen at the obligatory school entry health

examinations from February 1997 to August 1997. Their parents were given a questionnaire on risk factors for atopic diseases. The overall response rate by the parents was 76.2%. These data were linked with the routine data collected during the school entry health examination in all Bavarian children [17].

Inclusion criteria were German nationality, age from 5.00 to 6.99 years and full information on the outcome and explanatory variables leaving data of 4,222 girls and 4,543 boys (total 8,765) for the analyses. Height and weight were measured as part of the routine health examination. Overweight and obesity were defined as a body mass index (BMI) >90th and >97th percentile, respectively [21]. The reference values for the BMI were based on the age and sex specific distributions of all 115,530 German children who were investigated during the 1997 school health examination in Bavaria.

Questionnaire

The questions on smoking were: does the mother smoke? – (1) now? (yes/no), (2) during the child's 1st year of life? (yes/no), (3) during pregnancy? (yes/no), (4) in the year before pregnancy? (yes/no).

Statistical analyses

The prevalence of overweight and obesity by maternal smoking were estimated by different time periods: (a) before or before and after, but not during pregnancy (question 4 yes, question 3 no, questions 1 and 2 yes or no), (b) during pregnancy (question 3 yes, questions 1, 2 and 4 yes or no) and (c) after pregnancy only (questions 1 or 2 yes, questions 3 and 4 no). Confidence levels (CI) were based on binomial formulas. Crude and adjusted odds ratios (OR) for maternal smoking and overweight/obesity were calculated using Mantel Haenszel statistics and logistic regression analysis, respectively. Stratified analyses and the Breslow-Day test were used to assess effect modification of the association between the main exposure and the main outcome by sex. Breast-feeding, parental education, birth weight <2500 g and prematurity were included in the final logistic regression model because of a priori considerations. All calculations were carried out with the software package SAS version 6.12.

Results

There were 8,765 children with information on maternal smoking, weight and height. Some 5,919 mothers said that they had never smoked. There were 2,846 mothers smoking at any time. In 400 of these the precise period of smoking in relation to pregnancy could not be identified. There were 244 mothers who initiated smoking after pregnancy with the respective child only and 1,542 mothers who smoked before pregnancy and claimed to have abandoned smoking during pregnancy, of whom 1,139 returned to smoking after pregnancy. There were 660 mothers who stated explicitly that they had smoked throughout pregnancy, most of whom (614) were smokers before and after pregnancy as well.

The prevalence of overweight and obesity for maternal smoking during different time periods is shown in Table 1. The highest prevalence of overweight and obesity was observed in children of mothers who had smoked throughout pregnancy. In children whose mothers claimed to have abandoned smoking in pregnancy, however, the prevalence of overweight and obesity was only slightly lower. This contrasts with the prevalence in children of mothers who had taken up smoking after pregnancy only, which was similar to that in children of non-smoking mothers.

Mothers smoking during different time periods in relation to pregnancy differed considerably as shown in Table 2. Mothers who smoked throughout pregnancy were more likely to have premature or low birth weight children, to have less education and a slightly lower age and not to breastfeed than mothers who never smoked. Those who smoked before pregnancy or before and after pregnancy or after pregnancy only, were slightly less likely to breastfeed, to be highly educated and slightly younger than mothers who never smoked, but had similar prevalences regarding prematurity and low birth weight.

The increase in the risk for overweight and obesity in smoking mothers with reference to non smoking mothers was highest for maternal smoking throughout pregnancy, but only slightly lower in children of mothers who claimed to have stopped smoking in pregnancy. The risk for children of mothers who took up smoking after pregnancy only, however, was clearly not increased (Table 3). After stratification by sex, the ORs were almost identical (Breslow-Day Test, $P = 0.70$) excluding effect modification by sex. Breast-feeding, parental education, low birth weight and prematurity could only partly explain the different effects of maternal smoking throughout and before pregnancy on overweight/obesity (Table 3). Several other covariates such as number of siblings, number of persons living in the household, time

Table 1. Prevalence (95% CI) of overweight/obesity in German children in relation to maternal smoking

Maternal smoking[a]	Overweight (BMI >90th percentile)	Obesity (BMI >97th percentile)
Never smoked ($n = 5,919$)	9.1 (8.3–9.8)	2.8 (2.4–3.2)
Smoked		
Before pregnancy or before and after pregnancy but not throughout pregnancy ($n = 1,542$)	14.1 (12.4–15.9)	4.5 (3.6–5.7)
Throughout pregnancy ($n = 660$)	15.6 (12.9–18.6)	6.2 (4.5–8.3)
After pregnancy only ($n = 244$)	7.4 (4.4–11.4)	1.6 (0.4–4.1)

[a]The information was considered as inconclusive if maternal smoking was ticked as "yes" in one category but not as "yes" or "no" in the other categories ($n = 400$). Hence these were children whose mothers had smoked at some time but we do not know whether they only smoked during that stated period

Table 2. Factors associated with maternal smoking (95% CI)

	Any breastfeeding**	Prematurity (gestational age < 37 weeks)*	Birth weight < 2.500 g**	High level of parental education (μ 10 years)**	Mean maternal age (years)**
Never smoking	62.1 (60.9–63.4)	10.5 (9.7–11.3	7.5 (6.8–8.2)	60.9 (59.6–62.1)	27.8 (27.6–27.9)
Smoking after pregnancy	50.0 (43.7–56.3)	12.8 (8.5–17.0)	6.6 (3.4–9.7)	50.5 (43.8–57.1)	26.6 (25.7–26.8)
Smoking before pregnancy or before and after pregnancy but not throughout pregnancy	53.6 (51.1–56.1)	10.9 (9.4–12.5)	7.7 (6.4–9.0)	54.0 (51.4–56.5)	26.6 (26.3–26.8)
Throughout pregnancy	30.8 (27.3–34.4)	13.0 (10.4–15.5)	15.1 (12.3–17.8)	38.2 (34.4–42.1)	26.2 (25.9–26.6)

*$P = 0.20$ (chi-squared)
**$P < 0.001$ (chi-squared; ANOVA)

Table 3. Crude and adjusted ORs (95% CI) for the impact of maternal smoking on overweight/obesity with reference to non smoking mothers

Period of smoking	BMI > 90th percentile		BMI > 97th percentile	
	Crude OR	Adjusted OR[a]	Crude OR	Adjusted OR[a]
Smoking before pregnancy or before and after pregnancy but not throughout pregnancy ($n = 1{,}542$)	1.64 (1.39–1.94)	1.63 (1.37–1.94)	1.67 (1.26–2.22)	1.74 (1.29–2.34)
Throughout pregnancy ($n = 660$)	1.85 (1.47–2.33)	1.58 (1.23–2.04)	2.32 (1.63–3.30)	1.92 (1.29–2.86)
After pregnancy ($n = 244$)	0.80 (0.49–1.30)	0.80 (0.48–1.32)	0.59 (0.22–1.59)	0.63 (0.23–1.73)

[a]ORs adjusted for breast-feeding, parental education, low birth weight and prematurity

of introduction of solid food, and maternal age have also been considered as potential confounders, but none accounted for a change in OR by more than 10% individually.

Discussion

The main finding of this study is the higher prevalence of obesity in children of mothers who smoked in pregnancy. These results are consistent with those of Montgomery and Ekbom [9] who assessed the impact of maternal smoking in pregnancy on obesity in adults. Although adjustment for variables related to smoking throughout pregnancy such as birth weight and prematurity [2, 20] might produce a conservative estimate, the adjusted OR in our study (1.92; 95%CI 1.29–2.86) was considerably higher than that reported by Montgomery and Ekbom [9]. There are several possible explanations for the higher OR observed in our study: (1) the effect fades with age, (2) there were not enough confounding factors considered in our study and (3) the reference group for smoking throughout pregnancy is different (including mothers smoking early in pregnancy in the study reported by Montgomery and Ekbom [9]). Although most overweight children have a high risk for overweight in adulthood as well [1, 4] we cannot exclude a fading effect of maternal smoking without longitudinal data.

The number of potential confounders which could be considered in this study was limited since this study had originally been designed to identify causes of atopic disease [16]. Residual confounding in our study seems to be possible but is unlikely to account for the lower ORs reported by Montgomery and Ekbom [9] who adjusted for only one more possible confounder: the family social class (which is highly associated with parental education used as a surrogate for social class in our study).

There might be an effect related to smoking in early pregnancy, however, since a higher prevalence of obesity was also observed in children of mothers who smoked before pregnancy and claimed to have abandoned smoking in pregnancy. Most of these mothers are likely to have smoked at least until pregnancy was diagnosed and some even beyond. Inclusion of these children in the reference group might account for the lower risk estimates in Montgomery and Ekbom's study, which included mothers who smoked only in the first trimester in the reference group [9].

A higher risk of obesity in children of mothers who smoked either early or during the entire pregnancy might be surprising with respect to the long-known association of maternal smoking in pregnancy and low birth weight [2, 20]. Stopping smoking after the first trimester was found to reduce the effects of smoking on low birth weight to a large extent [5, 15]. Children of mothers who claimed to have smoked before pregnancy only had a similar proportion of low birth weight as children of non-smoking mothers suggesting that most of them stopped smoking during pregnancy. The effect of maternal smoking in pregnancy might at least in part be related to early exposure in pregnancy.

Long-term effects of maternal smoking in pregnancy on the risk of overweight might be related to long-term effects of nicotine exposure on neurobehavioural impulse control as shown in animal and human studies

[7, 8, 13, 19]. A lack of impulse control could be a result of the alterations in the dopamine and serotonin neurotransmitter systems that has been shown to occur in animal models after fetal nicotine treatment [18]. A lower school performance at the age of 14 years [14] and lower qualification achieved at the age of 23 years [6] in children of mothers who smoked in pregnancy after adjustment for confounding due to socioeconomic factors may be another hint of the effects of nicotine exposure in pregnancy on the central nervous system in humans. A possible lack of impulse control in children exposed to intrauterine tobacco products might result in a poorer satiation and a higher appetite accounting for an increased food consumption.

Alterations in the neuroendocrine metabolic regulation might be another explanation as suggested by a recent study reporting an association between maternal smoking in pregnancy and type 2 diabetes in the offspring [9].

Since a self-administered questionnaire at the offspring's school entry examination was used to assess maternal smoking during pregnancy retrospectively, we had no chance to validate reported smoking during pregnancy using objective measures. Non-differential misclassification would result in a bias towards unity. Differential reporting by parental education as indicator for social class, however, cannot be excluded. An overestimation of the risk of maternal smoking in pregnancy might occur if only mothers with a lower education reported their smoking in pregnancy correctly, whereas mothers with a higher education denied it. Results from other studies, however, suggest that self reported smoking is accurate in general [11, 12].

The data show that the effect of maternal smoking in pregnancy on obesity is reproducible in a different setting and at a younger age and provide indirect evidence for an effect related to early exposure in pregnancy. Although we lack information on a number of potential confounders and therefore could not adjust for these, the absence of a similar effect in an albeit small group of children whose mothers started smoking after pregnancy only suggests that exposure to smoke products in utero rather than family lifestyle factors associated with maternal smoking accounts for the higher prevalence of obesity in children of mothers who smoked.

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