Effects of Smoking Reduction during Pregnancy on the Birth Weight of Term Infants

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This study was undertaken to determine 1) whether reducing tobacco exposure during pregnancy increases the birth weight of term infants and 2) the relative effects of early- and late-pregnancy exposure to tobacco on infant birth weight. Data were obtained from the Smoking Cessation in Pregnancy project, conducted in public clinics in three states (Colorado, Maryland, and Missouri) between 1987 and 1991. Self-reported cigarette use and urine cotinine concentration were collected from 1,583 pregnant smokers at study enrollment and in the third trimester. General linear models were used to generate mean adjusted birth weights for women who reduced their tobacco exposure by 50 percent or more and for those who did not change their exposure. Regression smoothing techniques were used to characterize the relation between birth weight and early exposure and birth weight and third-trimester exposure. Reducing cigarette use was associated with an increase in mean adjusted birth weight of only 32 g, which was not significant ($p = 0.33$). As third-trimester cigarette use increased, birth weight declined sharply but leveled off at more than eight cigarettes per day. Findings were similar when urine cotinine concentration was used. Women who smoke during pregnancy may need to reduce to low levels of exposure (less than eight cigarettes per day) to improve infant birth weight. Am J Epidemiol 2001;154:694–701.

Received for publication November 15, 2000, and accepted for publication April 30, 2001.

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Smoking during pregnancy is a known cause of reduced infant birth weight, preterm delivery, and increased perinatal mortality (1–4). Although there is strong evidence that smoking cessation during pregnancy improves neonatal outcomes such as birth weight (5–7), only one in four pregnant smokers actually quits (8). One in three reports cutting back, however (9). Given that more women reduce their cigarette use than actually quit, it is important to ask whether reduction alone is beneficial to the infant.

Information available to clinicians regarding smoking reduction in pregnancy is conflicting. Windsor et al. propose that reducing tobacco exposure by 50 percent or more during pregnancy has beneficial effects on birth weight and that biochemically validated reduction rates should be considered a “behavioral indicator of harm reduction” (10, p. 648) in studies of smoking during pregnancy. However, this conclusion is based on the results of a study that did not directly address a 50 percent reduction (5). In contrast, the authors of several other papers have questioned the benefits of reduction in the absence of cessation (11–13). Before clear guidelines can be developed regarding smoking reduction during pregnancy, additional studies are needed.

Birth weight is frequently selected as an outcome in studies of the effects of tobacco exposure on the fetus. Most existing studies are based on the assumption that the dose-response relation between tobacco exposure and infant birth weight is linear; that is, researchers have assumed that each incremental increase in exposure yields a commensurate decrease in birth weight. However, evidence from several studies suggests that the sharpest decline in birth weight occurs at low levels of tobacco exposure (11, 12, 14). If the relation between tobacco exposure and birth weight is nonlinear, the effects of reduction may not be equal among women with different levels of exposure. Thus far, to our knowledge, no studies of the effects of smoking reduction on infant birth weight...
have included consideration of this nonlinear relation between tobacco exposure and birth weight.

We used data from a large smoking-cessation intervention trial to determine whether a 50 percent or greater reduction in tobacco exposure during pregnancy has an effect on the birth weight of term infants. Because there is no accepted standard for measuring tobacco exposure (15), we conducted our analysis by using both self-reported cigarette use and a biomarker, urine cotinine concentration (cotinine is a primary metabolite of nicotine). We stratified our findings by level of exposure at the time of study enrollment to determine whether a reduction in tobacco exposure benefits infants of lighter smokers more than those of heavier smokers. To overcome the limitations inherent in categorical analyses, we then used regression smoothing techniques to obtain more detailed information about the functional relation between birth weight and tobacco exposure in early and late pregnancy.

MATERIALS AND METHODS

Data source

We used data from the Smoking Cessation in Pregnancy project, a prospective, randomized trial conducted from 1987 through 1991 that included 5,572 women who received prenatal care in public prenatal clinics and Women, Infants, and Children programs in three states (Colorado, Maryland, and Missouri). This federally funded project was conducted to evaluate the effect of low-intensity smoking cessation counseling on quitting (16). Individual clinics were randomly assigned to provide their patients with newly developed written materials and brief smoking cessation messages or to provide usual prenatal care. Women in intervention clinics were encouraged to quit smoking; intervention protocols did not include recommendations to cut back as a goal.

All women who attended study clinics for their first prenatal visit were screened for eligibility. Those women who reported having smoked within 7 days before thinking they were pregnant or within 7 days before screening were considered smokers and were enrolled. Participants filled out questionnaires at enrollment (at the first or second prenatal visit, regardless of the gestational age), near the end of pregnancy (during the third trimester), and at the postpartum visit (around 6–12 weeks postpartum). On these questionnaires, women were asked how many cigarettes per day they had smoked in the previous 7 days. This number was their estimated daily cigarette use. Urine specimens were obtained for cotinine measurement within 2 days of the time when questionnaires were administered; for 97 percent of the patients, urine was collected on the same day that the questionnaire was filled out. The amount of time elapsed between the last cigarette smoked and the collection of urine was not elicited. Further details of the original study are presented elsewhere (16, 17).

Subjects

For this analysis, we restricted the original study population to Black or White women who delivered singleton, term infants (37 or more completed weeks’ gestation) with plausible birth weights (between the 0.5 and 99.5 percentiles for term infants, which is between 900 and 5,300 g). We included only women who delivered term infants in order to evaluate the effects of tobacco exposure on fetal growth independent of potential effects on preterm delivery. Subjects were required to have two sets of corresponding measures of tobacco exposure (self-reported cigarette use and urine cotinine concentration) separated by at least 8 weeks. We did this to exclude those women whose changes in tobacco exposure were of insufficient duration to affect birth weight. Ninety-seven percent of the study subjects were enrolled in the first or second trimester.

Birth weights were obtained from maternal interview at the postpartum visit when available. In Colorado and Missouri, data were merged with birth certificate records to obtain birth weights for infants of women lost to follow-up. In Maryland, data were merged with the state’s Maternity Summary Form. For 86 percent of the subjects, infant birth weights were obtained from maternal interview, and the remaining 14 percent were obtained from vital records. For 83 percent of the subjects, birth weights were available from both sources. For 92 percent of these, birth weights were within 30 g of one another.

Data analysis

Effects of 50 percent reduction in exposure on birth weight. We first used enrollment and third-trimester reported cigarette use to assign subjects to one of four different categories based on their pattern of exposure: “quit after enrollment,” “reduced,” “increased,” or “did not change,” as defined in table 1. We then assigned the same study subjects to similarly defined categories on the basis of urine cotinine levels (also defined in table 1). Women who quit before enrollment were analyzed separately. We computed mean adjusted birth weights for infants of women in each of the four categories by using general linear models to adjust for potential confounding factors elicited at enrollment: maternal age; race; education; parity; prepregnancy body mass index; Women, Infants, and Children program enrollment; caffeine consumption; alcohol consumption; whether or not the woman had a husband or partner; the state in which the clinic was located; and clinic nested within intervention/control status. We also adjusted for hours of exposure to environmental tobacco smoke in the third trimester, infant sex, and gestational age at delivery. Potential confounders with $p$ values of less than 0.20 were omitted from the final models. Women whose exposure did not change served as the reference group. Separate analyses were conducted using categories based on reported cigarette use and by urine cotinine concentration, respectively. Exposure to environmental tobacco smoke was not included in cotinine models because cotinine values reflect both active and passive exposure.

We stratified subjects by their level of exposure at enrollment (low, medium, and high) by using cutoff points defined a priori. We based these cutoff points on the functional relation between tobacco exposure and infant birth weight noted.
Subjects

Screening and enrollment questionnaires were available for 5,572 self-reported smokers. We limited our study population in the following way. A total of 4,005 women were of Black or White race, visited clinics of eligible size, and delivered term singleton infants with plausible birth weights. Of these, 1,922 women completed two prenatal visits, during which they provided urine samples and completed questionnaires. For 1,583 women, these visits were separated by at least 8 weeks, with the second visit occurring in the third trimester. Hence 1,583 women met all inclusion criteria.

Categories of tobacco exposure in these 1,583 women are summarized in table 1. A total of 224 women in the final study group reported at enrollment that they had quit smoking, 191 of whom reported at follow-up that they had not resumed smoking. An additional 1,359 women (86 percent) reported at enrollment that they were still actively smoking; in previous work (14) and on a review of the literature (5, 11–13). We defined exposure levels as: low = less than five cigarettes per day (this group includes active smokers who smoked an average of less than one cigarette per day), medium = 6–20 cigarettes per day, and high = 21–80 cigarettes per day. Exposure based on urine cotinine concentration was defined as: low = 86–1,000 ng/ml, medium = 1,001–2,000 ng/ml, and high = 2,001–10,000 ng/ml. At each level of enrollment exposure, we compared the mean adjusted infant birth weight of women who changed their tobacco exposure with that of women who did not change. We then tested whether a significant interaction existed between the level of exposure at enrollment and the pattern of exposure during pregnancy.

In all analyses, we included terms for random effects to account for the clustering of the data by clinic. These effects were not significant and were omitted from final models.

Functional relation between tobacco exposure and birth weight. We used generalized additive models (18) to determine the contribution of enrollment and third-trimester tobacco exposure to birth weight for both reported cigarette use and urine cotinine concentration while controlling for maternal age, race, parity, prepregnancy body mass index, state of residence, and infant sex. Because in these models women were not categorized according to changes in exposure during pregnancy, women who quit before enrollment were not excluded from this analysis. The level of exposure at both points in pregnancy was included in each model to estimate the independent contributions of tobacco exposure early and late in pregnancy to infant birth weight. Likelihood ratio tests of models with and without the smoothed tobacco exposure variable (cigarettes per day or cotinine concentration) were performed to test for significance of the association between tobacco exposure and birth weight. Nonparametric smoothing techniques (locally weighted regression or LOESS) (19) were used to examine the form of the relation between third-trimester tobacco exposure and birth weight. We visually inspected smoothed curves based on third-trimester exposure to identify the point at which the effects of tobacco on birth weight leveled off.

The study proposal, consent form, and questionnaires were reviewed and approved by the institutional review boards of the Centers for Disease Control and Prevention. Funding was supplied by the Centers for Disease Control and Prevention.

### RESULTS

#### Subjects

Screening and enrollment questionnaires were available for 5,572 self-reported smokers. We limited our study population in the following way. A total of 4,005 women were of Black or White race, visited clinics of eligible size, and delivered term singleton infants with plausible birth weights. Of these, 1,922 women completed two prenatal visits, during which they provided urine samples and completed questionnaires. For 1,583 women, these visits were separated by at least 8 weeks, with the second visit occurring in the third trimester. Hence 1,583 women met all inclusion criteria.

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These women reported smoking an average of 12.0 cigarettes per day. When we used a urine cotinine value of 85 ng/ml as the cutoff point for active smoking, 234 women had biochemical evidence that they were not actively smoking at enrollment, and 1,349 (85 percent) had evidence that they were actively smoking at enrollment. A total of 1,443 women had complete information available on all potential confounders and were included in the regression smoothing analysis.

Demographic characteristics varied among women with different exposure patterns. The mean ages of women who quit either before or after enrollment were lower than those of women who reduced, increased, or did not change their exposure. A greater percent of women who quit were nulliparous compared with women who reduced, increased, or did not change their exposure. Women who reduced their cigarette use smoked more cigarettes per day at the time of enrollment than did those whose exposure did not change (table 2). Similar findings were seen when urine cotinine concentration was used rather than reported cigarettes smoked per day (data not shown).

Women excluded from this analysis because they did not have corresponding measurements of tobacco exposure at two points in pregnancy separated by at least 8 weeks (\(n = 2,422\)) were more likely to be Black and had enrolled in the study later in pregnancy on average than women in the final analysis group. Other characteristics of the excluded women were similar (data not shown).

Cigarette use at enrollment was obtained for 99 percent of the excluded women, and birth weight information was available in 100 percent. Eighty-five percent of the excluded women reported actively smoking at enrollment.

### TABLE 2. Characteristics of study subjects by pattern of tobacco exposure during pregnancy (self-reported cigarettes smoked per day), Smoking Cessation in Pregnancy project, 1987–1991 (n = 1,583)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Quit before enrollment (%) (n = 224)</th>
<th>Quit after enrollment (%) (n = 127)</th>
<th>Reduced (%) (n = 277)</th>
<th>Increased (%) (n = 254)</th>
<th>Did not change (%) (n = 711)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education &lt;12 years</td>
<td>44.6</td>
<td>40.2</td>
<td>47.7</td>
<td>38.6</td>
<td>41.5</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White*</td>
<td>87.5</td>
<td>86.6</td>
<td>81.6</td>
<td>90.6</td>
<td>89.6</td>
</tr>
<tr>
<td>Black</td>
<td>12.5</td>
<td>13.4</td>
<td>18.4</td>
<td>9.5</td>
<td>10.4</td>
</tr>
<tr>
<td>Nulliparous</td>
<td>61.2</td>
<td>59.8</td>
<td>44.0</td>
<td>44.9</td>
<td>38.2</td>
</tr>
<tr>
<td>Husband/partner present</td>
<td>78.1</td>
<td>80.3</td>
<td>73.7</td>
<td>81.1</td>
<td>78.6</td>
</tr>
<tr>
<td>State of residence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colorado</td>
<td>34.8</td>
<td>29.1</td>
<td>21.7</td>
<td>22.8</td>
<td>25.0</td>
</tr>
<tr>
<td>Maryland</td>
<td>32.6</td>
<td>37.8</td>
<td>45.1</td>
<td>43.3</td>
<td>40.2</td>
</tr>
<tr>
<td>Missouri</td>
<td>32.6</td>
<td>33.1</td>
<td>33.2</td>
<td>33.9</td>
<td>34.8</td>
</tr>
<tr>
<td>Male infant</td>
<td>44.6</td>
<td>48.0</td>
<td>49.1</td>
<td>46.5</td>
<td>53.5</td>
</tr>
<tr>
<td>BMI† category</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;19.8</td>
<td>28.6</td>
<td>29.1</td>
<td>29.6</td>
<td>28.4</td>
<td>28.8</td>
</tr>
<tr>
<td>19.8–26</td>
<td>46.0</td>
<td>47.2</td>
<td>47.6</td>
<td>44.9</td>
<td>42.5</td>
</tr>
<tr>
<td>26.1–29</td>
<td>4.0</td>
<td>7.9</td>
<td>7.2</td>
<td>8.7</td>
<td>9.3</td>
</tr>
<tr>
<td>&gt;29</td>
<td>11.2</td>
<td>7.1</td>
<td>7.2</td>
<td>10.2</td>
<td>10.7</td>
</tr>
<tr>
<td>Missing</td>
<td>10.3</td>
<td>8.7</td>
<td>8.3</td>
<td>7.9</td>
<td>8.7</td>
</tr>
<tr>
<td>Mean age (years) (SD‡)</td>
<td>21.6 (4.5)</td>
<td>21.2 (4.3)</td>
<td>22.8 (4.9)</td>
<td>22.6 (4.4)</td>
<td>23.3 (4.5)</td>
</tr>
<tr>
<td>Mean gestational age at enrollment (weeks) (SD)</td>
<td>16.6 (5.2)</td>
<td>15.7 (5.0)</td>
<td>16.1 (5.5)</td>
<td>15.2 (5.4)</td>
<td>16.6 (5.4)</td>
</tr>
<tr>
<td>Mean cigarettes smoked per day (SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enrollment</td>
<td>0 (0)</td>
<td>5.1 (5.0)</td>
<td>18.0 (13.5)</td>
<td>6.2 (5.1)</td>
<td>13.1 (7.5)</td>
</tr>
<tr>
<td>Third trimester</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>5.4 (4.8)</td>
<td>17.7 (14.8)</td>
<td>12.3 (7.2)</td>
</tr>
<tr>
<td>Mean urine cotinine (ng/ml) (SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enrollment</td>
<td>23 (19)</td>
<td>812 (870)</td>
<td>2,788 (2,013)</td>
<td>1,110 (818)</td>
<td>2,127 (1,361)</td>
</tr>
<tr>
<td>Third trimester</td>
<td>21 (19)</td>
<td>26 (20)</td>
<td>877 (739)</td>
<td>2,643 (1,910)</td>
<td>1,958 (1,245)</td>
</tr>
</tbody>
</table>

* Includes Hispanic and non-Hispanic women.
† Prepregnancy body mass index (BMI).
‡ SD, standard deviation.
and these women reported smoking an average of 11.8 cigarettes per day. The mean infant birth weight for excluded women who reported at enrollment that they were active smokers was 3,214 g. The mean infant birth weight of excluded women who reported at enrollment that they had quit was 3,409 g.

**Effects of reduction in exposure measured by cigarettes per day**

Women who quit smoking before enrollment and those who quit after enrollment delivered infants with the highest adjusted mean birth weights (3,492 and 3,491 g, respectively). Overall, the mean adjusted infant birth weight for women who reduced their cigarette use at enrollment and the pattern of exposure during pregnancy was 201 g heavier than that for light smokers whose cigarette use did not change (p = 0.33) (table 3). However, after stratification by level of cigarette use at enrollment, the mean adjusted infant birth weight for women with low exposure who reduced their cigarette use was 32 g heavier compared with women whose cigarette use did not change (p = 0.03) (table 3). We found no significant interaction between the level of cigarette use at enrollment and the pattern of exposure during pregnancy (p = 0.2).

### TABLE 3. Change in mean adjusted birth weight among women who changed their tobacco exposure during pregnancy compared with those who did not change their exposure (self-reported cigarettes smoked per day or urine cotinine concentration), Smoking Cessation in Pregnancy project, 1987–1991 (n = 1,583)

<table>
<thead>
<tr>
<th>Pattern of exposure</th>
<th>Did not change</th>
<th>Quit after enrollment</th>
<th>Reduced</th>
<th>Increased</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cigarettes per day at enrollment</strong></td>
<td>No.</td>
<td>Mean adjusted birth weight (g)</td>
<td>Difference in mean adjusted birth weight (g)</td>
<td>95% CI</td>
</tr>
<tr>
<td>Low (£5)</td>
<td>95</td>
<td>3,162</td>
<td>72</td>
<td>296</td>
</tr>
<tr>
<td>Medium (6–20)</td>
<td>511</td>
<td>3,202</td>
<td>43</td>
<td>324</td>
</tr>
<tr>
<td>High (&gt;20)</td>
<td>33</td>
<td>3,249</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>639</td>
<td>3,205</td>
<td>115</td>
<td>286</td>
</tr>
</tbody>
</table>

**Pattern of exposure = reported cigarettes smoked per day**

| **Urine cotinine at enrollment (ng/ml)** | No. | Mean adjusted birth weight (g) | Difference in mean adjusted birth weight (g) | 95% CI | No. | Mean adjusted birth weight (g) | Difference in mean adjusted birth weight (g) | 95% CI | No. | Mean adjusted birth weight (g) | Difference in mean adjusted birth weight (g) | 95% CI |
| Low (86–1,000) | 148 | 3,305 | 62 | 175 | 47, 303 | 24 | 40 | −144, 226 | 148 | −50 | −147, 47 |
| Medium (1,001–2,000) | 224 | 3,177 | 13 | 198 | −44, 440 | 44 | 16 | −124, 155 | 90 | 54 | −52, 160 |
| High (2,001–10,000) | 324 | 3,175 | 7 | 218 | −104, 540 | 94 | 21 | −78, 119 | 43 | 16 | −121, 152 |
| Total | 696 | 3,216 | 82 | 197 | 94, 301 | 162 | 21 | −52, 95 | 291 | 0 | −63, 63 |

**Effects of reduction in exposure measured by urine cotinine concentration**

When urine cotinine concentration was used to define patterns of tobacco exposure, women who quit smoking before enrollment delivered infants with the highest adjusted mean birth weight (3,524 g), followed by women who quit after enrollment (3,413 g). The mean adjusted infant birth weight for women whose urine cotinine concentration reduced was only 21 g heavier compared with those whose cotinine concentration did not change; this finding was not significant (p = 0.57) (table 3). After stratifying subjects by cotinine level at enrollment, we found no significant increase in mean adjusted infant birth weight among women who reduced their cotinine concentration compared with those whose cotinine level did not change (table 3). We found no significant interaction between the urine cotinine level at enrollment and the pattern of exposure during pregnancy (p = 0.8).

**Tobacco exposure and birth weight: regression smoothing techniques**

As cigarette use at enrollment increased (adjusted for third-trimester cigarette use and other variables previously
Smoking Reduction in Pregnancy

As described, there was no coinciding change in infant birth weight (figure 1a). We found no significant association between the number of cigarettes smoked per day at enrollment and birth weight ($p = 0.84$) (figure 1a).

As third-trimester cigarette use increased (adjusted for cigarette use at enrollment and other variables previously described), infant birth weight initially declined sharply. However, birth weight attained its lowest point at eight cigarettes per day, and then no further decline was observed at higher levels of exposure (figure 1b). The association between third-trimester exposure and infant birth weight was significant ($p < 0.0001$). Among women who reported exposure levels of more than 20 cigarettes per day ($n = 77$), we could not determine with certainty the nature of the relation between cigarette exposure and birth weight because of small numbers. This is reflected by the wide confidence bands (indicated by the dashed lines in figures 1 and 2).

Our findings were slightly different when we used urine cotinine to measure tobacco exposure. In this case, as urine cotinine concentration at enrollment increased (adjusted for third-trimester urine cotinine concentration and other variables previously described), there was a slight decrease in birth weight at low levels of cotinine and no further change in birth weight at higher levels of exposure (figure 2a). This relation was significant ($p = 0.03$). As urine cotinine concentration in the third trimester increased (adjusted for enrollment urine cotinine concentration and other variables previously described), birth weight initially declined sharply and then reached its lowest point, at approximately 700 ng/ml. No further declines were observed at higher levels of cotinine.

DISCUSSION

We studied the potential benefits of reducing tobacco exposure during pregnancy in two ways. We first compared mean adjusted birth weights for infants of women with different exposure patterns (those who reduced by at least 50 percent vs. those who did not change) using both self-reported cigarette use and urine cotinine concentration. We found benefits of reduction only among women who reported low levels of cigarette use at enrollment. We then used regression smoothing techniques to study the dose-response relation between birth weight and tobacco exposure both early and late in pregnancy. We found the strongest association between infant birth weight and tobacco exposure when we used third-trimester exposure levels. Furthermore, the detrimental effects of tobacco exposure on birth weight leveled off at eight cigarettes per day. Since it appears that most of the effects of smoking on birth weight occur during the third trimester and at exposure levels of less than eight cigarettes per day, the goal of reduction should be to reduce to less than eight cigarettes per day rather than to cut back by 50 percent.

Other studies

Previous studies of the effects of tobacco exposure reduction on birth weight have not been conclusive. Li et al. (5) compared mean birth weights of women who reduced their salivary cotinine concentration by 20 ng/ml (if baseline cotinine was <100 ng/ml) or 60 ng/ml (if baseline cotinine was >100 ng/ml) and found a 92-g increase in birth weight among infants of reducers that was not statistically significant. They also observed a 241-g improvement in infant birth weight...
FIGURE 2.  

2a, Adjusted birth weight as a function of urine cotinine at the time of enrollment with all adjustment variables held fixed at their means, and 2b, adjusted birth weight as a function of urine cotinine in the third trimester for 1,583 pregnant smokers enrolled in the Smoking Cessation in Pregnancy project, 1987–1991. The regression model adjusted for the mother’s age, race, parity, and body mass index; the state in which the clinic was located; the infant’s sex and gestational age; and urine cotinine in the third trimester (a) and at enrollment (b). Complete data were available for 1,443 women who were included in the final model. —, smoothed value of birth weight; ----, 95% confidence bands.

among White reducers with baseline salivary cotinine levels of more than 100 ng/ml that was statistically significant. Secker-Walker et al. (13) used regression equations to estimate the effects of a 50 percent reduction in self-reported cigarette use and urine cotinine concentration on birth weight and predicted improvements of 89 and 33 g, respectively. They concluded that women who continue to smoke throughout pregnancy are unlikely to see substantial improvements (>100 g) in infant birth weight unless they are able to reduce use by 10 cigarettes per day or more. They also noted that the “average infant birth weights were similar for women smoking between 6 and 20 cigarettes per day” (13, p. 972). In an earlier study, Hebel et al. (12) noted a nonlinear relation between tobacco exposure and infant birth weight in which the effects of increasing cigarette use leveled off at approximately five cigarettes per day. The authors concluded that among women who smoked at least 10 cigarettes per day, “only those who reduced their smoking to less than 5 cigarettes per day were able to modify their risk for low birth weight” (12, p. 488). Our findings that most of the detrimental effects of tobacco on birth weight occur at less than eight cigarettes per day and that a 50 percent reduction in exposure at enrollment (1–5 cigarettes/day) are consistent with studies conducted by Hebel et al. and by Secker-Walker et al. Our study extends these earlier works, however, by applying regression smoothing techniques to a large study population. In addition, using both self-reported cigarette use and urine cotinine concentration provides an opportunity to look for consistency of effects across different measures of tobacco exposure.

Methodological considerations

In this study, we observed substantial improvements in birth weight (>200 g) among infants of women who reported low cigarette use who then reduced exposure. However, we observed no improvement in birth weight among infants of women with low cotinine concentration who then reduced their tobacco exposure. One potential limitation of using cotinine as a measure of tobacco exposure is that the serum cotinine concentration of sporadic smokers (such as those who smoke on weekends only) may not be at a steady state. Hence, the urine cotinine concentrations used in our study may not have accurately reflected tobacco exposure, and this could have resulted in the exposure misclassification of some women. This type of misclassification could have diminished potential differences in infant birth weight between women who truly reduced their exposure and those who did not change.

In previous studies of the effects of smoking reduction on birth outcomes, researchers have relied on categorizing women according to changes in exposure (5, 13). This approach was part of our analytic strategy as well; however, it is inherently limited. It diminishes power to detect exposure effects because information contained within categories of exposure is lost. To overcome this limitation, we also performed regression by using smoothing, which allowed us to characterize the functional relation between tobacco exposure and birth weight in detail. We found that third-trimester tobacco exposure is a more important determinant of birth weight than is early exposure. This is consistent with previous studies of smoking cessation in which women who quit smoking during pregnancy delivered infants who weighed as much as infants of never smokers (7, 12). Because we did find a significant association between urine cotinine concentration early in pregnancy and birth weight, we cannot rule out the possibility that early tobacco exposure has some minor effect on fetal growth. However, any effects of early exposure on birth weight are likely to be overshadowed by effects of third-trimester exposure. Finally, we found that most of the deleterious effects of tobacco on infant birth weight appear to occur at low levels of exposure (i.e., less than eight cigarettes per day or less than 700
ng/ml of urine cotinine). Hence, women with medium levels of exposure who reduced their cigarette use may not experience improvements in infant birth weight unless they achieve levels of less than eight cigarettes per day. In contrast, women who smoke fewer than eight cigarettes per day but who succeed in reducing exposure may see substantial improvements in birth weight, even if they are unable to quit. Our ability to interpret our findings at high levels of tobacco exposure is limited by the small number of heavy smokers in this study. It is possible that infants of women with high levels of exposure may benefit from reduction, as described by Li et al. (5).

This study has a number of limitations. The study population consists of low-income women who used public clinics. There may be aspects of how women in this population smoke cigarettes and report their use that are unique to this group. As in many studies of this nature, data for many study subjects were incomplete, which may have led to bias. It is reassuring, however, that women from the larger study group who were excluded from this analysis did not differ greatly from those included in the analysis by self-reported cigarette use at enrollment or by infant birth weight. Finally, although we required 8 weeks between enrollment and third-trimester measurements, we do not know the exact time when reduction in exposure took place. Hence, meaningful changes in exposure may not have occurred in all women categorized as reducers.

The nature of the relation between tobacco exposure and other outcomes remains unclear. Therefore, we should not extrapolate from our findings about the effects of smoking reduction on infant birth weight to other outcomes. Smoking reduction may have other unmeasured fetal and maternal benefits.

Conclusions

Our data suggest that much of the detrimental effect of tobacco on the birth weight of term infants occurs at less than eight cigarettes/day. In addition, we found little evidence that reducing tobacco exposure improves infant birth weight, although there appeared to be some benefit among women who report low levels of exposure at enrollment. Therefore, it seems likely that women who smoke during pregnancy need to reach low levels of exposure to see improvements in infant birth weight. To achieve infant birth weights approaching those of never smokers, they will need to quit entirely.

Future studies of the relation between smoking and fetal growth should incorporate the concept of a nonlinear relation between tobacco exposure and birth weight. It appears to be more appropriate to define reduction according the level of exposure achieved by the end of pregnancy, rather than as a percent change.

ACKNOWLEDGMENTS

This study was funded by the Centers for Disease Control and Prevention. The authors acknowledge the important contributions of Dr. W. Harry Hannan at the National Center for Environmental Health, Centers for Disease Control and Prevention, and of the Smoking Cessation in Pregnancy project staff, especially the state coordinators, Nancy Miller (Missouri), Nancy Salas (Colorado), and Joan Stine (Maryland).

The study proposal, consent form, and questionnaires were reviewed and approved by the institutional review boards of the Centers for Disease Control and Prevention.

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