The aim of this investigation was to identify the sources of postnatal exposure to tobacco smoke at 1 month of age and to examine their relation to sudden infant death syndrome (SIDS). The Tasmanian Infant Health Survey was a prospective cohort study undertaken from 1988 to 1995. It involved 9,826 infants (89% of eligible infants) at higher risk of SIDS. Subsequently 53 eligible infants died of SIDS. Hospital interviews were available on 51 and home interviews on 35 SIDS infants. Urinary cotinine assays were conducted using gas-liquid chromatography (r² = 100). Within a predictive model that explained 63% of urinary cotinine variance, the strongest predictor of cotinine and also of SIDS was maternal smoking, though the effects of prenatal and postnatal smoking could not be separated. However, for particular smoking-related behaviors, there was a discordance between prediction of cotinine concentration and prediction of risk of SIDS. If smoking mothers did not smoke in the room with the baby, the cotinine level in the infant's urine was reduced by a little more than a half (p = 0.009), but this was not associated with a reduction in SIDS risk (odds ratio = 1.09, 95% confidence interval 0.47–2.55). Similarly, the presence of other adult resident smokers was associated with a 63% increase in urinary cotinine (p = 0.047) but not with increased SIDS risk (odds ratio = 0.69, 95% confidence interval 0.34–1.40). However, the study lacked the power to detect modest effects, that is, those altering risk less than twofold. Am J Epidemiol 1999;149:593–602.

cotinine; prospective studies; sudden infant death; tobacco smoke pollution

Editor’s note: For a discussion of this paper and for the authors’ response, see pages 603 and 607, respectively.

The incidence of sudden infant death syndrome (SIDS) has fallen by approximately 50 percent in several countries during the early 1990s following successful campaigns to reduce the prevalence of prone infant sleeping position (1). A large fraction of the remaining SIDS deaths is occurring in infants who have not been placed prone to sleep, and there is a need to identify preventable causes of these deaths.

A leading contender is infant exposure to tobacco smoke, either in utero or postnatally. The recent Confidential Enquiry (Inquiry) into Stillbirths and Deaths in Infancy (CESDI) study in the United Kingdom is the first to provide data on factors associated with risk for SIDS in a population where prevalence of prone sleeping position has fallen to very low levels following the “Back to Sleep” campaign in 1991.
control study, although paternal smoking did appear to be independently related to risk after adjustment for maternal smoking during pregnancy, the parents' report of infant total daily exposure to tobacco smoke did not (2).

The Tasmanian Infant Health Survey is a cohort study from which data on the association between sleeping position and SIDS have previously been reported (24). This study provided a unique opportunity to examine the association between the major contributing factors to postnatal exposure to environmental tobacco smoke, as identified by urinary cotinine analysis, and SIDS using prospective data.

MATERIALS AND METHODS
The cohort study

A prospective cohort study was conducted to investigate the etiology of SIDS in Tasmania from 1988 to 1995. It involved the six major obstetric hospitals in the state that represented approximately 93 percent of live births. Infants born in these hospitals were assessed using a scoring system to predict those at higher risk of SIDS (24). Infants with a sufficiently high perinatal score were eligible to join the study. Multiple births were automatically included. The eligibility criteria and study methods are discussed in more detail elsewhere (25, 26).

Standard study measurements were collected by research assistants in three stages. First, an interview was conducted when the infant was 4 days old. Information collected included the number of cigarettes smoked per day by the mother during each trimester of pregnancy; whether the mother lived with someone who smoked cigarettes or a pipe during pregnancy; the number of cigarettes per day smoked in the mother's presence inside and outside the house; and the time spent in the same room as someone smoking, inside and outside the home.

Second, a home visit took place usually during the fifth postnatal week. Premature infants (≤36 weeks' gestation) were seen at 40 weeks' postconceptual age and at least 2 weeks after hospital discharge. Infant and home environment measurements were made, and a comprehensive verbal questionnaire was administered. Information was collected on the amount smoked (cigarettes/day) by the mother and other household adults; the number of adult smokers in the house; and whether the mother or other adult smoked in the same room as the infant, or while feeding the infant, or while holding the infant. A telephone interview was conducted when the infant was 12 weeks of age. Data were collected on "others" rather than fathers because the cohort had a large proportion of unmarried mothers (25). For the
The purpose of this report, not smoking in the same room as the infant is referred to as “good smoking hygiene.” Infant deaths under 12 months of age from 1988 to 1996 were monitored for Tasmania. Sudden infant death syndrome was classified as a cause of death after postmortem examination by a hospital pathologist and death scene investigation.

The Tasmanian case-control study

A population-based retrospective case-control study was also conducted. Retrospective data were collected by interview with parents of SIDS infants approximately 6 weeks after death. From October 1, 1988, to December 31, 1995, 93 percent (100/107) of parents of SIDS infants participated in the interview, which is described in more detail elsewhere (27). For this report, retrospective data on SIDS cohort infants on whom prospective data were not available at 1 month of age were examined.

Case definition

Sudden infant death syndrome was classified as a cause of death after postmortem examination by a hospital pathologist and death scene investigation on sudden unexpected infant deaths for infants younger than 12 months. There appears to be little difference among pathologists in the various centers of Australia in recording SIDS deaths (28). This view has been substantiated by an international observer (29). Since 1987, all hospital pathologists in Tasmania have been asked to follow a standard autopsy procedure for these deaths. Since 1992, pathologists have been asked to follow the Australasian SIDS Autopsy Protocol, which is similar to the protocol that was used during 1988 through 1991.

Urinary cotinine assays

To provide biologic validation of the questionnaire data on fetal and infant exposure to tobacco smoke, infant urine was collected on 105 infants of a possible 121 visited at home from August 2, 1995, to October 13, 1995, in the study in southern Tasmania in 1995. Cotinine, a major metabolite of nicotine with a half life of approximately 20 hours (30), provides a valid measure of average human environmental tobacco smoke exposure over time (31). The urine samples were frozen and sent by air courier to the National Poisons Unit, New Cross Hospital, London, England, for assay by gas-liquid chromatography (30, 32). Results were available for 100 infants, and all of these had detectable concentrations of cotinine. The sensitivity of cotinine assays at the laboratory was high, with cotinine concentrations as low as 0.1 ng/ml detectable (32).

Statistical methods

The distribution of cotinine concentrations was highly skewed (skewness = 3.86, mean = 22.4 ng/ml, median = 6.6 ng/ml, range = 0.2–274.4 ng/ml). In order to reduce the effects of the few large values and to better satisfy the distributional assumptions of the statistical methods, the natural logarithms of the cotinine concentrations were used. Their distribution was approximately symmetric (skewness = 0.20, mean = 1.91, median = 1.89). All results presented in the text and tables are for the logged cotinine concentrations. In investigating the effects of various factors on cotinine, we used linear models (33) with (log) cotinine as the outcome variable. The antilog of an estimated regression coefficient in the log (cotinine) model gives an estimate of the multiplicative effect of the corresponding factor on cotinine. Such multiplicative effects are roughly analogous to the odds ratios in the SIDS models. Logistic regression (33) was used to investigate the associations of various factors with SIDS. To assess if the eligibility criteria for the cohort affected the relation between smoking and SIDS, we built multivariate models that included terms for the scoring system components (male sex, birth weight, maternal age under 19 years, seasons of birth, intention to bottle-feed, duration of second stage of labor, and multiple birth). Where matching was undertaken to examine the effects of confounding, the matched data were analyzed using conditional logistic regression. A statistical assessment of confounding included an assessment of whether the rate was altered by 10 percent (34). Dose-response effects, such as for categories of amount smoked, were investigated by using a dichotomous variable for smoker versus nonsmoker and dummy variables for each smoking category beyond the first. Where there appeared to be a linear trend across the smoking categories, we investigated by replacing the dummy variables with a linear term (plus the smoker/nonsmoker indicator). Statistical analyses were performed using SAS version 6.09 software (35).

RESULTS

Study progress

From January 1, 1988, to December 31, 1995, 11,055 live birth infants were eligible for inclusion in the study. Of these infants and their families, 10,562 participated in the hospital interview, and 9,826 (89 percent) participated in the hospital and home inter-
view. The median infant age at home interview was 4.7 (interquartile range, 4.3–5.7) postnatal weeks or 44.1 (interquartile range, 42.6–45.1) postconceptional weeks. Fifty-three eligible infants later died of SIDS, of whom 51 (96 percent) participated in the hospital interview. Seven of these infants died prior to the arranged home visit, one infant's family refused to participate, one infant was excluded (>12 weeks in the hospital), and seven home visits were not achieved within the specified time frame. Infants who died prior to the arranged home visit died at the following postnatal ages (completed weeks): 1, 2, 3, 4, 5, 8 weeks (i.e., 37, 43, 41, 43, 45, 42, and 40 postconceptional weeks, respectively). Thus, home interview data are available on 35 infants, 66 percent of the infants who met the cohort entry criteria, and 81 percent of those who were eligible for home visit.

The study sample consisted of 69.0 percent (6,781/9,826) male infants, 21.9 percent (2,155/9,826) infants of low birth weight (<2,500 g), 19.8 percent (1,948/9,825) infants born to teenage mothers, 32.9 percent (3,230/9,826) infants born in March-April, 26.5 percent (2,601/9,826) infants born in May-July, and 40.7 percent (3,995/9,826) infants born in August-February. At hospital interview, 58.6 percent (5,761/9,824) had mothers who intended to fully breastfeed.

### TABLE 1. The relation between sources of fetal and infant tobacco smoke exposure, infant urinary cotinine levels, and sudden infant death syndrome (SIDS), Tasmanian Infant Health Survey, 1988–1995

<table>
<thead>
<tr>
<th>Sources of tobacco smoke exposure</th>
<th>Mean value of log of infant urinary cotinine (ng/ml)</th>
<th>No. of SIDS cases</th>
<th>No. of SIDS controls</th>
<th>Odds ratio for SIDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>No maternal prenatal smoking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any maternal prenatal smoking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mother did not live with a smoker during pregnancy</td>
<td>56</td>
<td>2.73</td>
<td>&lt;0.0001</td>
<td>0.36</td>
</tr>
<tr>
<td>Mother did live with a smoker during pregnancy</td>
<td>44</td>
<td>2.55</td>
<td>&lt;0.0001</td>
<td>0.14</td>
</tr>
<tr>
<td>During pregnancy, on average, no cigarettes were smoked each day in mother's presence at home</td>
<td>50</td>
<td>1.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>During pregnancy, on average, one or more cigarettes were smoked each day in mother's presence at home</td>
<td>50</td>
<td>2.80</td>
<td>&lt;0.0001</td>
<td>0.34</td>
</tr>
<tr>
<td>During pregnancy, on average, no cigarettes were smoked each day outside mother's presence</td>
<td>46</td>
<td>1.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>During pregnancy, on average, one or more cigarettes were smoked each day outside mother's presence</td>
<td>54</td>
<td>2.49</td>
<td>&lt;0.0001</td>
<td>0.17</td>
</tr>
<tr>
<td>No maternal postnatal smoking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal postnatal smoking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No postnatal smoking by other adult household residents</td>
<td>56</td>
<td>1.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postnatal smoking by other adult household residents</td>
<td>39</td>
<td>2.67</td>
<td>&lt;0.0001</td>
<td>0.17</td>
</tr>
<tr>
<td>Mother never smokes while in same room as infant</td>
<td>68</td>
<td>1.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mother sometimes or always smokes in the same room as infant</td>
<td>32</td>
<td>3.07</td>
<td>&lt;0.0001</td>
<td>0.27</td>
</tr>
<tr>
<td>Mother's partner or other adult never smokes while in same room as infant</td>
<td>50</td>
<td>1.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mother's partner or other adult sometimes or always smokes while in the same room as infant</td>
<td>50</td>
<td>2.52</td>
<td>&lt;0.0001</td>
<td>0.16</td>
</tr>
<tr>
<td>Baseline (no maternal postnatal smoking)</td>
<td>47</td>
<td>0.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal postnatal smoking 1–10 cigarettes per day</td>
<td>28</td>
<td>2.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal postnatal smoking 11–20 cigarettes per day</td>
<td>21</td>
<td>3.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal postnatal smoking ≥21 cigarettes per day</td>
<td>4</td>
<td>2.95</td>
<td>&lt;0.0001</td>
<td>0.38</td>
</tr>
<tr>
<td>Baseline (mother and other adult household residents do not smoke)</td>
<td>38</td>
<td>0.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postnatal smoking by mother only</td>
<td>18</td>
<td>2.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postnatal smoking by other adult household residents only</td>
<td>6</td>
<td>1.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postnatal smoking by mother and other adult household residents</td>
<td>33</td>
<td>2.89</td>
<td>&lt;0.0001</td>
<td>0.38</td>
</tr>
<tr>
<td>Baseline (no prenatal or postnatal maternal smoking)</td>
<td>42</td>
<td>0.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal prenatal smoking only</td>
<td>5</td>
<td>1.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal postnatal smoking only</td>
<td>2</td>
<td>0.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal prenatal and postnatal smoking</td>
<td>51</td>
<td>2.87</td>
<td>&lt;0.0001</td>
<td>0.41</td>
</tr>
</tbody>
</table>

* Numbers in parentheses, 95% confidence interval.
Assessment of the relation between tobacco smoke exposure, urinary cotinine, and SIDS

Comparison of univariate prediction of cotinine levels and also of SIDS. The relation of several variables measuring fetal and infant tobacco smoke exposure to urinary cotinine and SIDS is shown in table 1. On univariate analysis, the cotinine levels were significantly higher in infants who were reported as exposed to smoke from any source. Among the dichotomous variables, maternal postnatal smoking and maternal antenatal smoking had a similar association with urinary cotinine, explaining just over a third of the cotinine variation. This similarity is not surprising, as the majority of women had a similar smoking pattern during and after pregnancy. Among the 35 SIDS cases, 25 of the mothers smoked both during the pregnancy and in the postnatal period. Seven did not smoke at either time. Among the non-SIDS group, 4,318 mothers smoked both during pregnancy and in the postnatal period, whereas 4,686 did not smoke at either time of the 9,728 on whom data on both were available. That is, 93 percent did not change smoking behavior. Maternal exposure to tobacco smoke during pregnancy (e.g., cigarettes smoked in the mother’s presence at home) was also a strong explanatory variable for cotinine in the univariate analysis (table 1). Urinary cotinine levels were higher \((p < 0.0001)\) if the infant’s mother smoked postnatally (figure 1). Lower cotinine levels were reported for infants of mothers who had not smoked in the same room as the baby (table 1). Among mothers who smoked, the cotinine level was higher among those who sometimes or always smoked in the same room as the baby (mean log cotinine = 3.07 ng/ml) than among those who stated they never smoked in the same room as the baby (mean log cotinine = 2.36 ng/ml) \((p = 0.06)\). The following factors were not significantly associated with urinary cotinine: maternal age, paternal unemployment, use of windows in infants’ bedroom during the night, whether the infant slept alone or not, and resident density per room.

On univariate analysis, antenatal maternal smoking and postnatal maternal smoking were associated with a higher risk of SIDS, while the mother’s reporting that she never smoked in the same room as the baby was associated with lower risk for SIDS (table 1). Although they were predictors of infant urinary cotinine, a history of smoking by other adult residents and whether others smoked in the same room as the baby were not significantly associated with SIDS. The risk of SIDS among infants who lived in a home where the mother and other adult residents smoked (OR = 2.83, 95 percent CI 1.09–7.37) was not higher than for infants who lived in a home where only the mother smoked (OR = 4.48, 95 percent CI 1.65–12.13). The separate effects of prenatal and postnatal maternal smoking could not be separated because so few mothers changed smoking status.

Comparison of multivariate prediction of cotinine levels and also of SIDS. After constructing several general linear models, we developed a model explaining 65 percent of the variance in urinary cotinine (table 2). The addition of amount smoked daily by the mother (in categories) or infant sex did not improve prediction for urinary cotinine. The components of this model were then examined in relation to their association with SIDS. The model examines the effects of smoking exposures and birth weight for different groups of infants (table 2). As this is essentially a subgroup analysis, confidence intervals are wide, and the likelihood of type II error is high. The risk estimates for SIDS are provided with 95 percent confidence intervals to provide information on their direction and magnitude. Smoking by other household residents was a minor determinant of cotinine levels, leading to a 63 percent increase in urinary cotinine, but did appear to relate to SIDS. Good maternal smoking hygiene was an important independent predictor of lower cotinine levels, decreasing cotinine levels by approximately one half, but was not associated with SIDS.

Assessment of the relation between tobacco smoke exposure and SIDS after adjustment for other variables

Maternal prenatal smoking. The risk estimate for antenatal smoking (unadjusted OR = 3.34, 95 percent
CI 1.52–7.36) was reduced slightly after adjustment for the components of the perinatal scoring system (adjusted OR = 2.58, 95 percent CI 1.14–5.79), but the scoring system did include a term for infant birth weight, a possible intermediate. There was no dose-response effect for category of smoking. After adjustment for whether or not the mother smoked during pregnancy, smoking during any specific trimester of pregnancy did not add further to the prediction of SIDS. Among singleton births, prenatal maternal smoking was associated with reduced placental weight (mean difference = 9 g, \( p = 0.02 \)) and reduced birth weight (mean difference = 184 g, \( p = 0.0001 \)). Among singleton births, the association of prenatal smoking with SIDS (unadjusted OR = 3.20, 95 percent CI 1.38–7.40) was reduced by 14 percent after adjustment for prematurity, placental weight, and birth weight (adjusted OR = 2.76, 95 percent CI 1.18–6.46).

**Maternal postnatal smoking.** The risk for maternal postnatal smoking remained after further adjustment for smoking by other adult residents in the house (adjusted OR = 3.67, 95 percent CI 1.65–8.18). The effect of maternal postnatal smoking was reduced after adjustment for whether the infant was bottle-fed or not at the home visit (adjusted OR = 2.98, 95 percent CI 1.38–6.43), but there was no evidence of multiplicative interaction between bottle-feeding and maternal smoking in relation to SIDS (\( p = 0.61 \)). The risk estimate for postnatal maternal smoking (unadjusted OR = 3.38, 95 percent CI 1.58–7.23) was reduced after adjustment for components of the scoring system (adjusted OR = 2.50, 95 percent CI 1.13–5.49). However, the risk estimate for maternal postnatal smoking was increased, rather than reduced, after adjustment for the socioeconomic variables low maternal education, paternal unemployment, private health insurance, and marital status (married, living together vs. others) (adjusted OR = 3.78, 95 percent CI 1.52–9.40). Maternal postnatal smoking remained significant with odds ratios >3 after individual adjustment for hospital of birth, private medical care, preterm birth (<37 weeks), sleeping alone, maternal satisfaction with motherhood, season of birth, delayed first immunization, prone sleeping position, birth after May 1, 1991 (this date indicates the start of intervention to reduce prone sleeping), or family history of asthma. The risk estimate for postnatal smoking remained significant, with a less than 10 percent change in the odds ratio, after individual adjustment for consumption of folate preparations during pregnancy, vitamin supplementation during pregnancy, administration of antihistamines, the infant’s history of breathing problems, firstborn status, history of an upper respiratory tract infection (cold) by 1 month of age, low maternal education, and delayed start to antenatal care; episodes of perspiration were unrelated to febrile illness or air freshener use in the baby’s bedroom. There was no interaction between maternal

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**TABLE 2. Factors predicting urinary cotinine levels and also their relation to sudden infant death syndrome (SIDS), Tasmanian Infant Health Survey, 1988–1995**

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Prediction of urinary cotinine (n = 95)</th>
<th>Risk estimate for SIDS (cases, n = 34; controls, n = 9,464)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relative change in log cotinine (regression coefficient)</td>
<td>Odds ratio</td>
</tr>
<tr>
<td></td>
<td>( \rho ) value</td>
<td>( \rho ) value</td>
</tr>
<tr>
<td>Maternal postnatal smoking versus no maternal postnatal smoking for infants who were fully or partially breastfed</td>
<td>3.74 (( p = 0.0001 ))</td>
<td>5.29 (1.16–24.11) ( \dagger )</td>
</tr>
<tr>
<td>Maternal postnatal smoking versus no maternal postnatal smoking for infants who were exclusively bottle-fed</td>
<td>1.36 (( p = 0.0001 ))</td>
<td>2.35 (0.73–7.62)</td>
</tr>
<tr>
<td>Other household residents smoke versus no other smokers in the household</td>
<td>0.49 (( p = 0.047 ))</td>
<td>0.69 (0.34–1.40)</td>
</tr>
<tr>
<td>Infant exclusively bottle-fed versus full or partial breastfeeding for infants of nonsmoking mothers</td>
<td>0.11 (( p = 0.72 ))</td>
<td>2.72 (0.67–10.96)</td>
</tr>
<tr>
<td>Increasing birth weight (per kg) for infants of nonsmoking mothers</td>
<td>0.042 (( p = 0.79 ))</td>
<td>0.47 (0.23–0.98)</td>
</tr>
<tr>
<td>Increasing birth weight (per kg) for infants of smoking mothers</td>
<td>-0.47 (( p = 0.004 ))</td>
<td>0.39 (0.23–0.65)</td>
</tr>
<tr>
<td>Mother never smokes in same room as infant</td>
<td>-0.76 (( p = 0.009 ))</td>
<td>1.09 (0.47–2.55)</td>
</tr>
</tbody>
</table>

* The two multivariable models (one for log cotinine outcome, one for SIDS as an outcome) had all the factors listed above included in the single model. Their effects are adjusted for all the other variables in the table that applied to the specific infant. Dummy variables were used for factors and combinations of factors. Birth weight was scaled as weight in kg after subtracting 3 kg. So, for instance, an infant whose mother smoked had its actual birth weight (minus 3 kg) used for the term “increasing birth weight for infants of smoking mothers.”

\( \dagger \) Numbers in parentheses, 95% confidence interval.
postnatal smoking and whether or not the infant slept in a bedroom alone.

To further examine the possible effect of confounding, including the prone sleeping position, we matched the case infants to control infants on sleeping position, season of birth (month of birth and two closest months in the same season), infant sex, and mother’s age (within 3 years) and further adjusted for low birth weight, bottle-feeding, duration of second stage of labor, and multiple birth. This gave an odds ratio of 3.44 (95 percent CI 1.49–7.94) for maternal smoking.

The unadjusted odds ratios for maternal postnatal smoking by daily amount smoked were as follows: 1–10 cigarettes (unadjusted OR = 1.07–7.32); 11–20 cigarettes (unadjusted OR = 3.01, 95 percent CI 1.22–7.42); and more than 20 cigarettes/day (unadjusted OR = 5.31, 95 percent CI 2.04–13.81). After adjustment for scoring system components, the postnatal risk by smoking category was the following: 1–10 cigarettes/day (adjusted OR = 2.08, 95 percent CI 0.79–5.48); 11–20 cigarettes/day (adjusted OR = 2.15, 95 percent CI 0.85–5.47); and over 20 cigarettes/day (adjusted OR = 4.69, 95 percent CI 1.74–12.58). The test for trend was not significant (p = 0.14). The level of agreement between prospective and retrospective data was high for maternal smoking in case infants on whom both sets of data were available, with a kappa of 0.91 (95 percent CI 0.74–1.08), but lower for smoking by other residents (kappa = 0.60, 95 percent CI 0.31–0.89). For 14 of the cohort infants who subsequently died from SIDS, retrospective data were available on postnatal smoking, but prospective data were missing. The substitution of retrospective data for these infants for the cohort data set did not substantially alter the findings in relation to postnatal maternal smoking and SIDS, providing an odds ratio for maternal postnatal smoking of 3.61 (95 percent CI 1.88–6.93). The trend for increasing risk by increasing smoking category among smoking mothers was now significant in the full model (p = 0.047).

Maternal smoking hygiene. Among mothers who smoked postnatally, the effect of not smoking in the room with the infant was not significantly associated with SIDS (unadjusted OR = 1.27, 95 percent CI 0.57–2.86). After adjustment for scoring system components and maternal postnatal smoking, the effect of not smoking in the same room as the baby was not associated with SIDS. Further adjustment for marital status, paternal unemployment, low maternal education, and private health insurance did not alter this, providing an adjusted odds ratio of 0.85 (95 percent CI 0.33–2.14). We then examined whether the effect of the mother’s not smoking in the same room was modified by the scoring system components. After adjustment for the scoring system components, the effect of the mother’s actively smoking in the same room was modified (p = 0.0013) by the age of the mother. For mothers under 19 years of age, active smoking in the same room was not associated with SIDS (OR = 0.29, p = 0.68) but was associated with SIDS among older mothers (OR = 4.00, p = 0.003).

Smoking by other adult residents. An effect on risk for smoking by other residents was not evident with (adjusted OR = 0.72, 95 percent CI 0.48–1.46) or without (unadjusted OR = 1.10, 95 percent CI 0.56–2.16) adjustment for maternal postnatal smoking. The risk effect remained nonsignificant after further adjustment for the scoring system components marital status, paternal unemployment, maternal postnatal smoking, low maternal education, and private health insurance. Smoking by other household residents remained unimportant when the data on cohort cases collected retrospectively were used for cohort cases with missing data, providing an adjusted odds ratio (adjusted for maternal postnatal smoking) of 0.80 (95 percent CI 0.44–1.44). Again, after adjustment for the scoring system components, the adverse effect of smoking by others in the same room was greater (p = 0.0064) for babies with older mothers (OR = 2.38, p = 0.058) than for babies with mothers aged 19 years or younger (OR = 0.32, p = 0.58).

DISCUSSION

As in previous retrospective studies, we found a positive association between the mother’s smoking and risk of SIDS but, as in many other studies (22), this could not be separated from prenatal maternal smoking because behavior was similar before and after birth. However, the prospective design and the availability of information on what predicted the infant’s urinary cotinine postnatally enabled us to examine whether factors in the postnatal environment that were important sources of environmental tobacco smoke were also related to risk of SIDS. This study did not provide evidence that sources of postnatal environmental tobacco smoke for infants, apart from the exposure obtained via the mother’s smoking, were associated with SIDS. In particular, smoking by other household residents and maternal smoking hygiene, although independent predictors of infant cotinine levels, were not significantly associated with a higher overall risk of SIDS.

The cohort study collected standard information over time with a high overall response rate of 89 percent. However, some case infants died before interview. Maternal smoking risk has been previously reported to vary by age of death (7, 14, 20). To examine possible selection bias due to the unavailability of prospective
postnatal smoking data for these cases, retrospective data from the case-control study that target all SIDS deaths in the state were utilized for these cases to allow their inclusion in a separate set of analyses. Similar estimates for maternal and other residents' smoking were obtained when these data were included.

This cohort is not a representative sample of live births. However, in order for the results of an analytical cohort study to be generalizable to other populations, it is not necessary for the cohort to be representative of the community from which it was selected (36, 37). The components of the scoring system used to define study eligibility have been adjusted for in multivariate analyses. The findings in this study are similar to those of the Tasmanian case-control study, where maternal postnatal smoking was strongly related to SIDS (matched OR = 3.96, 95 percent CI 1.91–8.24), but smoking by other residents was not (matched OR = 1.31, 95 percent CI 0.70–2.44) (38).

The infant's urinary cotinine has previously been found to relate well to atmospheric nicotine as measured by an ambient passive nicotine monitor ($r = 0.81$) (39). Good maternal smoking hygiene, that is, the infant's not being in the same room when the mother smokes, has been previously related to the infant's cotinine levels (40). The assay for measuring urinary cotinine in the infant was highly sensitive. Table 2 shows that active maternal smoking was more strongly associated with urinary cotinine if the infant was partially or fully breastfed, reflecting the breast milk cotinine ingested by the infant (40). An inverse association between birth weight and cotinine level was demonstrated for infants of smoking mothers. The urinary cotinine of the infant almost certainly reflects its passive exposure to smoke from others in the house and/or the mother's smoking hygiene as well as active maternal smoking. That these exposures are not associated with increased risk of SIDS brings into question the causal link postulated between passive inhalational smoking by the infant after birth and SIDS.

However, the lack of apparent effect of these factors on SIDS may be a consequence of the small number of cases. If one were to extrapolate from the effect of each of these factors on cotinine to a predicted effect on SIDS, using the model in table 2, the expected odds ratios would be approximately 1.6 and 0.5 for smoking by others in the house and for the mother's not smoking in the same room, respectively. The observed odds ratios for SIDS of 0.69 and 1.09, respectively, are quite dissimilar to these predicted values from urinary cotinine but are not outside what might be expected due to chance. This study did have sufficient power to detect odds ratios greater than 1.96 for smoking by others and less than 0.44 for mothers who never smoked in the same room as the baby. Risk estimates of this magnitude have been found for these smoking variables in some but not all previous case-control studies. In the New Zealand case-control study (19), paternal smoking (unadjusted OR = 2.41, 95 percent CI 1.92–3.02) was only associated with SIDS risk if the mother smoked, and smoking by others (unadjusted OR = 1.54, 95 percent CI 1.20–1.99) was only weakly associated with SIDS. In the National Maternal and Infant Health Survey, the risk of SIDS was also not significantly increased for infants of nonsmoking mothers if a household member smoked (16). However, in the recent CESDI study (2), the risk associated with paternal smoking was 2.50 (95 percent CI 1.48–4.22), after controlling for confounders including maternal smoking during pregnancy and infant sleep position. In the California case-control study, odds ratios of 3.46 for fathers' smoking and 2.18 for other live-in adults were obtained after adjustment for maternal smoking during pregnancy, sleep position, and other variables (17). This study also found that not smoking in the same room decreased the maternal smoking risk by half and the paternal smoking risk by more than half, from an odds ratio of 8.5 to one of 3.5 (17). These results are too heterogeneous to justify the extraction of a likely overall effect, and only one study (17) has examined parental smoking hygiene in detail.

Another explanation may be that the apparent lack of effect of these factors on SIDS is the result of confounding by other factors. It might be expected that these other factors would be associated with socioeconomic status. For example, infants of parents who are unmarried and not living together are more likely to have mothers who smoke in the room where the infant is located (26). In this study, the relatively small effect of controlling for social class argues against this being of major significance in this cohort but does not rule out this possibility.

Alternatively, the higher proportion of younger mothers in this sample may have reduced the overall adverse effect of active smoking in the same room on SIDS, as the association of this variable appeared to be modified by maternal age, with its adverse effect more evident among children of older mothers. This interaction remained after adjustment for the scoring system. Unfortunately, the small number of SIDS cases did not allow us to examine whether this apparent effect modification was due to an uneven distribution of potential confounders, such as marital arrangements or prenatal or postnatal amount smoked differing between mothers by age.

A dose-response trend for maternal postnatal smoking on SIDS risk was significant only when retrospective data were substituted for cases with missing data. Comparison of retrospective versus prospective report-
ing by the same case parent shows, as previously reported, good agreement for the data on maternal smoking, but the agreement was less for smoking by others. The latter should be taken into consideration when interpreting risk estimates in retrospective studies for smoking by those other than the mother.

The lack of association between factors increasing postnatal environmental tobacco smoke and SIDS in this study is consistent with the hypothesis that the principal effect of maternal smoking on SIDS operates prenatally. There are several biologic pathways that could be responsible for such an effect. The previous demonstration of potentiation of maternal smoking risk in the presence of maternal anemia during pregnancy provides evidence that at least part of the effect of maternal smoking on SIDS is mediated during pregnancy, possibly through the mechanisms of chronic fetal hypoxia (9). The association between prenatal smoking and low birth weight is well known (41, 42).

In conclusion, maternal active smoking is clearly related to SIDS, but the effects of prenatal and postnatal smoking could not be separated. In this cohort, the postnatal passive smoke exposure associated with smoking by the mother in the presence of the infant and with postnatal smoking by others was related to infant urinary cotinine levels but was not significantly related to SIDS. However, the study lacked the power to detect modest effects, that is, those altering risk less than twofold. The results of this study support the case for an emphasis on prenatal smoking cessation programs aimed to reduce maternal smoking but indicate also the need to collect further data on the specific association of infant postnatal environmental tobacco smoke exposure with SIDS to clarify its independent contribution to sudden infant death syndrome.

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