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World Health Organization

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Report from a symposium held at the Annual Conference of the International Society for Environmental Epidemiology (ISEE)

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Executive summary

Introduction

Around half of the world's population still relies on solid fuels for everyday energy needs, 2.4 billion on biomass (wood, animal dung, crop wastes) and 0.6 billion on coal. These fuels are typically used indoors or in partly enclosed cooking areas, burnt in poorly vented, inefficient stoves, and leading to very high levels of exposure to smoke which contains products of incomplete combustion. Most heavily exposed are women of child-bearing age and young children. Women usually continue with their domestic and cooking role throughout pregnancy, so the developing foetus is also indirectly exposed. Studies of urban air pollution and environmental tobacco smoke (ETS) have shown that several combustion pollutants – including carbon monoxide and small particles – are linked to adverse pregnancy outcomes; still births and low birth weight. These pollutants are also prominent in smoke from solid fuel used in developing country homes, so there is good reason to expect that this exposure may also impact on pregnancy outcomes in these settings. This report summarises the evidence linking such exposure to low birth weight (LBW) and stillbirth, as reviewed in a symposium held at ISEE 2005 in Johannesburg.

Methods

Representatives of research groups which have carried out recent studies of biomass smoke pollution and LBW and/or stillbirth in developing countries were invited to present their findings at the symposium. In addition, recent work on ambient air pollution and LBW from the state of California was also represented. Key issues for future studies were identified. Following the symposium, a preliminary literature review was conducted using PubMed: combining exposure and outcome terms yielded 190 studies, of which 44 were retained as relevant for review of abstracts. This, together with further contact with researchers in the field, provided only one new study which is included in this review. Data has been extracted, and quality assessed by one author (NB).

Results

(i) Low birth weight

Five studies are included: one cross-sectional survey, two cohort studies, one case-control study and one randomised controlled trial. Differences in exposure were expressed as biomass vs. clean fuel for four studies, and biomass in open fires vs. ventilated (chimney) stoves in one. The timing of birth weight measurement varied between studies, and only two assessed gestational age. For *mean birth weight*, the range of differences for 'high' vs. 'low' exposure across four studies were from 59 to 175 gm lower weight with the higher exposure. All estimates were adjusted, and three were statistically significant. For *% LBW* (defined as <2,500 gm), one study reported an adjusted odds ratios (OR) for high exposure vs. low exposure of 1.74 (95% CI: 1.2, 2.5), one an unadjusted OR of 1.26 (0.77, 2.05), and another OR of 1.20 for term LBW ($p<0.05$) and 1.50 for pre-term LBW ($p<0.05$) but results from multivariate analysis were not reported and are presumed non-significant. There was no evidence of statistical heterogeneity among these estimates as all 95% confidence intervals overlap.

(ii) Stillbirth

Three studies are included, one case control, one cross-sectional survey, and one cohort. Two obtained information on stillbirths from health records and interviews, the other relied on recall at interview (*1*). For all three studies, differences in exposure were expressed as biomass vs. cleaner fuel. All adjusted for confounding, with odds ratios for high exposure vs. low exposure ranging from 1.44 to 1.90. All three estimates were statistically significant, and again there was no evidence of statistical heterogeneity among these estimates as all 95% confidence intervals overlap.

(iii) Ambient air pollution studies

A recent ambient (outdoor) pollution study carried out in California found an adjusted odds ratio of 1.26 (1.03, 1.50) for high vs. low $PM_{2.5}$ exposure during pregnancy, among singleton births of 40 weeks gestation. This exposure difference was associated with a mean difference in birth weight of -36 gm (95% CI: -16.5, -55.8). No independent effect of CO on birth weight was seen. $PM_{2.5}$ exposure was also associated with a small increase in the risk of pre-term birth (OR = 1.15, 95% CI: 1.07, 1.24), again with no independent effect of CO exposure.

Conclusion

This review has found consistent impacts of solid fuel smoke exposure on both LBW and stillbirth. Although the body of evidence is still relatively small, these findings are consistent with studies on exposure to outdoor air pollution and ETS. The ISEE symposium concluded that a modest number of additional, high quality studies of the adverse pregnancy outcomes are required, paying particular attention to assessment of exposure and gestational age. It was concluded that, if the risk estimates are confirmed by further studies, since high proportions of pregnant women are exposed to solid fuel smoke in developing countries, and the prevalence of both LBW and stillbirth is high, the population attributable risk associated with this exposure is likely to be substantial.

1 Introduction

Background

Nearly half of the world's population, some 3 billion people, rely on solid fuels (wood, animal dung, crop residues, and coal) for their everyday household energy needs. Much of this fuel is burned in open fires and simple stoves with inadequate ventilation, causing very high levels of smoke exposure – particularly for women and young children. A WHO Comparative Risk Assessment report estimated that this exposure is responsible for around 1.5 million excess deaths annually (*2;3*). This estimate, based on reliable evidence of health outcomes, was restricted to acute lower respiratory infections in children up to 5 years and chronic obstructive lung disease in adults, as well as lung cancer in adults in places where only coal was used. However, emerging evidence shows that household air pollution increases the risk of other important conditions, including tuberculosis, asthma, cataract, low birth weight (LBW) and perinatal mortality, although only a few studies have been published for these health outcomes (*2;4*).

This report, based on the ISEE 2005 symposium, focuses on the links between pollution due to solid fuel use and birth weight, stillbirth and mortality. At the time of preparation, we were aware of only two published studies from developing countries on indoor air pollution and birth weight, and only one linking this exposure to stillbirths.

Since pregnant women in countries with high rates of (i) solid fuel use and (ii) LBW and perinatal mortality are rarely able to avoid exposing themselves and their unborn children to household air pollution from cooking and other activities, even a modest increase in relative risk for these conditions could translate into a substantial risk for the population. LBW remains a very important risk factor for pneumonia and other serious adverse health outcomes for infants in developing countries.

Aims and objectives

- To review and summarize the current and emerging evidence for links between indoor air pollution from solid fuel use and low birth weight and perinatal mortality.
- To identify research to confirm what is already known.
- To consider appropriate research designs and settings to meet identified research needs.
- To initiate planning in respect of (a) methods and (b) possible settings to assist the development of proposals for future research to guide policy on child health.

Intended outcomes

For researchers on indoor air pollution and child health, this symposium took stock of what is known about the risk of LBW and perinatal mortality (for which the evidence is plausible but still limited) and identifies key research priorities. A subsequent workshop will discuss methodological issues to advance the research agenda, and will identify potential research collaboration and study settings.

This article summarizes the studies given at the symposium (in section 2), presents the evidence in tabular form from studies in developing countries (in section 3), and concludes with ideas for further research identified during discussions at a workshop that followed the symposium (section 4).

2 Symposium presentations

Summaries of the five presentations at the symposium are given in this section.

2.1 Low birth weight among a cohort of Guatemalan children: indoor air pollution as a contributing factor

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Background

A low birth weight (LBW) of <2500 grams is used to delimit populations at risk for adverse health outcomes in infancy and adulthood. Recent studies have found associations between LBW and common airborne pollutants in developing countries, including environmental tobacco smoke (ETS) and biofuel smoke (*5;6*). Carbon monoxide is a known feto-toxicant and has been associated with poor fetal growth (*7–9*). National data from Guatemala estimate the incidence of LBW to be 13%, although approximately 22% of newborns are not weighed at birth. Only 17% of indigenous women deliver with the assistance of skilled personnel and over 86% of rural, indigenous women deliver at home (*10*). Low birth weight is under-reported and undoubtedly much higher than the estimates provided from national survey data.

Between October 2002 and December 2004, the RESPIRE (Randomized Exposure Study of Pollution Indoors and Respiratory Effects) trial in Guatemala enrolled 534 households of Mam-speaking indigenous Mayans residing in 23 communities in the Western Highlands to participate in a study of the impact of indoor air pollution (IAP) on the incidence of acute lower respiratory infection (ALRI) among <18-month-old children.[1] A secondary aim of the study was to examine IAP, specifically particulate matter (PM) and carbon monoxide (CO), as a risk factor for low birth weight outcomes among pregnant women enrolled in the study. Households with pregnant women or children <4 months old were randomly assigned to receive an improved, vented stove called a *plancha*, or to continue cooking over their open fire until the end of the study (at which time they received a *plancha*).

[1] For more information about the ALRI study, please visit the Guatemala Stove Intervention Trial web site at: http://ehs.sph.berkeley.edu/guat/admin/admin/fso.asp

Methods/sample

A total of 275 women had a baseline pregnancy examination by a physician, which included a medical history, urine exam, blood pressure check, and assessment of fetal growth (fundal height). The women were then followed up weekly in their homes by trained field workers, and were referred to a physician if any pregnancy-related warning signs or symptoms were noted. Of these 275 women, 15 were not pregnant or were lost to follow-up, two delivered twins, and one had a child with trisomy 21. There were five miscarriages and four stillbirths. During the course of the study, an additional 31 "second" pregnancies were observed. A total of 286 singleton births monitored by project staff delivered in their homes, and fieldworkers attempted to visit the home as soon as possible to measure the birth weight. Birth weight monitoring began in November 2002 using a scale accurate to 100 grams. Beginning in August 2003, birth weights were measured using a SILTEC BS-1 scale, which was accurate to within 10 grams. Babies were undressed except for a light shirt provided by the project staff to standardize the clothing weight. Gestational age was not assessed; 48-hour monitoring of the pregnant women was done every 3 months using Gastec passive diffusion carbon monoxide (CO) tubes. A total of 386 CO tubes were worn by pregnant women during either their first or second study pregnancy. In a study by Naeher et al., passive diffusion CO tubes (Draeger) were demonstrated to be a fairly good surrogate for mothers' personal exposure to kitchen PM2.5 (24 hour) with a Spearman correlation coefficient of 0.65 (*11*). CO data are available for this report as PM data are not yet available.

Results

Exposure assessment

All the pregnant women in the study wore a CO tube at least once during their pregnancy. The *plancha* group's exposure to CO was approximately 20% lower than that for the control open-fire group: mean (95% CI) 48-hour values were 1.97 (1.72, 2.27) and 2.49 (2.09, 2.89) respectively (t-test, unequal variance, $p = 0.047$), as shown in Table 1. First trimester exposures were monitored in "second" pregnancies but are not shown in Table 1; the reduction was greater than in the first pregnancies, and may reflect an overall awareness about avoidance of indoor air pollution during the project. Furthermore, CO reductions were more pronounced among pregnant mothers as compared to non-pregnant mothers who wore the CO tubes. In a multivariate regression model (results not shown), *plancha* status significantly reduced CO exposures by 1.52 ppm (t-test: –11.42, $p <0.000$) among all women; pregnancy further reduced CO exposures by 0.33 ppm (t-test: –2.45, $p <0.014$) even while controlling for cooking stove type.

The RESPIRE study recruitment procedure was designed to monitor ALRI in young children: as a result, many of the pregnant women received the *plancha* stove short-

TABLE 1

Mean personal measurement of carbon monoxide levels (ppm) among 255 "first pregnancies", by trimester and stove type

Trimester	*Plancha*			Open fire		
	Mean	SD	N	Mean	SD	N
First	1.67	.85	8	2.05	0.97	7
Second	2.07	2.32	51	2.75	4.16	48
Third	2.00	1.83	117	2.41	2.13	112
Total	**1.97**	**1.93**	**176**	**2.49**	**2.83**	**167**

ly before, or in a few cases, after delivery. To allow for this, women were reclassified according to the first day the *plancha* could be used after the 35-day period needed to condition and "dry" the stove. Under this reclassification, 29 of the *plancha* women actually resided in open fire households throughout their pregnancy, and 5 of the open-fire households had a second pregnancy after the *plancha* stove was built, thus they were reclassified as *plancha* households. In order to illustrate the effect of this adjustment, the results will be presented with and without re-classification.

Demographic characteristics

Table 2 provides baseline information about the participants enrolled during their "first" study pregnancy. Almost 58% of the women were in their third trimester at the time of the initial examination, 35% were in their second trimester, and only 7% were in their first trimester. The mothers and fathers in the *plancha* group tended to be two years younger on average, and reported fewer pregnancies. There was no statistically significant difference between the two groups for the number of abortions, Caesarean sections or deceased children. None of the women reported a personal history of tuberculosis, diabetes, renal or heart disease. One woman reported a history of hypertension. Two of the women reported a personal history of alcoholism; 60 (23%) reported that an immediate family member, in most cases identified as the spouse, was an alcoholic. Eighteen (7%) of the women had a known personal history of prior anaemia. Borderline hypertension was observed in only one woman; the remaining 254 blood pressure measurements were normotensive. Both systolic and diastolic blood pressures were almost 2 mmHg higher in the open-fire group as compared to the *plancha* group, but these differences were not significant. Urine examination revealed no women with glycosuria and less than 3% with proteinuria or leukorrhoea. Average height for women in the study was 144.6 cm. There was no monitoring of weight gain at the start of (or during) the pregnancy.

Birth weight outcomes

Birth weights of 188 out of 286 live birth newborns (65.7%) were measured within 48 hours of delivery, while 225 (78.7%) were measured within one week;[1] 50 (22.2%) of all measured births were <2500 grams. Table 3 presents the birth weights for the two groups according to randomized allocation. For the purpose of this analysis, the groups were then reclassified by whether the *plancha* was constructed and ready for use prior to the birth. In the group that had babies who were weighed within 48 hours of birth, 18 of the women assigned to the *plancha* group actually were using open fires up until their child's birth. Among those women assigned to the *plancha* group and who had babies who were weighed within 1 week of birth, 29 women were still using the open fire during the pregnancy. For first pregnancies, none of the women used the *plancha* during the first trimester, while 84.6% of the women received the *plancha* in the third trimester (median number of days with *plancha* before delivery: 46 (IQR, 58 days). By the second pregnancy, 73.7% of the women assigned to the *plancha* group were using the *plancha* throughout the gestational period (median number of days with *plancha* before delivery: 280 (IQR, 116 days). Five of the women assigned to the open-fire group had a second pregnancy after their planchas were constructed.

[1] All home birth weights = 236. This analysis excludes two of four twins measured at birth (an obvious error), with birth weight measuring 6.6 kg at 3 days, and 8 repeat measurements made on children within the one-week period.

TABLE 2

Demographic characteristics of participants enrolled during pregnancy, by stove type

Characteristic	N	Plancha	Open fire	Test
Mother's age (years):		25.6 (*6.7*)	27.3 (*6.2*)	T = 2.18
mean (*SD*)		134	126	*p <0.03*
n	260			
Mother's age group:				
N (%)				
14–19 years		29 (21%)	14 (11%)	$\chi^2 = 10.81$
20–25 years		51 (38%)	38 (30%)	p <0.01
26–35 years		41 (31%)	61 (49%)	
36–42 years		13 (10%)	13 (10%)	
Father's age (years):*				
mean (*SD*)		27.7 (*7.7*)	30.0 (*6.9*)	T = 2.47
n	259	133	126	*p <0.01*
Child's sex (first child)				
N (%)				NS
Male	113	59 (45%)	54 (45%)	
Female	138	72 (55%)	66 (55%)	
Missing	9			
Child's sex (2nd child)*				
N (%)				NS
Male	18	9 (60%)	9 (60%)	
Female	12	6 (40%)	6 (40%)	
No. of pregnancies:				
mean (*SD*)		4.7 (*3.1*)	5.3 (*2.8*)	t = 1.51
n	257	133	124	*p = 0.13*
First pregnancy				
N (%)	21	13 (9.7%)	8 (6.3%)	NS
More than five births		43 (32.1%)	49 (38.9%)	$\chi^2 = 1.44$
N (%)				*p = 0.23*
Diastolic BP (mmHg):*				
mean (SD)				
n	259	66.7 (*8.0*)	68.2 (*8.1*)	t = 1.52
		134	125	*p = 0.13*

* Missing = 1 BP: blood pressure

TABLE 3

Birth weight outcomes, by randomization group and by reassignment (*plancha* not ready for use prior to delivery)

Stove type	Birth weight at <48 hours (kg) N (mean ± SD)	Birth weight at <1 week (kg) N (mean ± SD)
Assigned group through randomization:		
Total	188 (2.749 ± 0.400)	225 (2.796 ± 0.442)
Plancha	98 (2.761 ± 0.416)	121 (2.825 ± 0.450)
Open fire	90 (2.736 ± 0.384)	104 (2.764 ± 0.431)
Plancha in use during pregnancy:		
Plancha in use	80 (2.776 ± 0.412)	92 (2.786 ± 0.405)
Open fire	108 (2.729 ± 0.392)	133 (2.804 ± 0.467)

TABLE 4

Birth weight, difference in grams due to *plancha* (unadjusted), based on actual assignment group and reclassification group

Stove type	*Plancha* (n)	Difference in grams	95% Confidence interval	p-value
Weighed at <48 hours:				
Plancha, assigned	98	25	[-90, 140]	0.67
Plancha, reclassified	80	46	[-70, 163]	0.43
Weighed at <1 week:				
Plancha, assigned	121	60	[-55, 176]	0.30
Plancha, reclassified	92	-19	[-137, 99]	0.75

Table 4 shows the mean improvement in birth weight (in g) for the *plancha* group compared to open-fire controls for the original allocation groups and for the re-classified groups. For both the <48 hour and <1 week measurement groups, there is a modest increase in birth weight difference, although this never reaches statistical significance. Fieldworkers measured babies in open-fire households 9 hours later, on average, than in *plancha* households (t-test = 1.66, p = *0.09*). This difference of a few hours may not be clinically important, although it may partially explain the reversal in trend in Table 4, which shows a small difference of 19 g favouring the open-fire group (NS).

As shown in Table 5, the absolute number of births <2500 g was less in the *plancha* households as compared to the open-fire households at 48 hours and at 1 week, and was further strengthened by reclassification of *plancha* use during pregnancy. However,

TABLE 5

Low birth weight by stove type and reclassification

Stove type	< 2500 grams N (%)	≥ 2500 grams N (%)	Total N (%)
Birth Weight at < 48 hours			
Assigned group through randomization:			
Open fire	22 (24.4%)	68 (75.6%)	90 (100%)
Plancha	22 (22.4%)	76 (77.6%)	98 (100%)
Total	44 (23.4%)	144 (76.6%)	188 (100%)
			Risk Ratio 1.08, 95% CI (0.65, 1.82)
Plancha in use during pregnancy:			
Open fire	26 (24.1%)	82 (75.9%)	108 (100%)
Plancha in use	18 (22.5%)	62 (77.5%)	80 (100%)
Total	44 (23.4%)	144 (76.6%)	188 (100%)
			Risk Ratio 1.07, 95% CI (0.63, 1.81)
Birth Weight at < 1 week			
Assigned group through randomization:			
Open fire	26 (25.0%)	78 (75.0%)	104 (100%)
Plancha	24 (19.8%)	97 (80.2%)	121 (100%)
Total	50 (22.2%)	175 (77.8%)	225 (100%)
			Risk Ratio 1.26, 95% CI (0.77, 2.05)
Plancha in use during pregnancy:			
Open fire	30 (22.5%)	103 (77.5%)	133 (100%)
Plancha in use	20 (21.7%)	72 (78.3%)	92 (100%)
Total	50 (22.2%)	175 (77.8%)	225 (100%)
			Risk Ratio 1.04, 95% CI (0.63, 1.71)

TABLE 6

Multivariate model of birth weight outcome measured at <1 week

Variable	Difference in grams (_)	t	*p*	95% CI
Intercept	2954	15.67	0.00	[2582, 3326]
Plancha, reclassified	59	0.70	0.48	[-107, 226]
Days with *plancha*	0.68	0.81	0.42	[-0.9, 2.3]
Maternal age	-8.3	-1.11	0.27	[-23.1, 6.5]
Birth history: primipara	-127	-1.04	0.30	[-369, 114]
Birth history: "grand" multipara (>5 births)	175	1.83	0.07	[-13.7, 364]

the risk ratios were not significant, reflecting the increased instability and low power to detect significant differences within this small sample.

A multivariate model was constructed to examine other potential explanatory variables that might influence birth weight. These variables were included in the model based on significance in bivariate analyses or as supported by the literature. A socioeconomic indicator (ratio of the number of economic providers to the number of household members) and whether or not the father smokes were also included in the model, but eliminated as they did not improve the stability of the estimates, as shown in Table 6.

Discussion

The Guatemalan Randomized Intervention Stove Trial offered a unique opportunity to monitor the health of pregnant women and subsequent perinatal outcomes in one of the poorest regions in Guatemala. There are several limiting factors to the study. First, the study was designed to examine the children's respiratory health; among some of the recruited households with pregnant women, stove construction was not completed until after the child was born. Only 13 of the women had a *plancha* throughout their (second) pregnancies, thus limiting differential exposure to the third trimester, as most of the women would have used open fires during the first and/or second trimester. Second, methodological limitations include lack of information about maternal weight gain and nutritional factors, gestational age assessment, inability to reach all home births within 48 hours, and accuracy to only 100 grams of the weighing scale used in the first 10 months of the study, all of which could bias the findings toward the null. Third, although *plancha* stoves reduced women's personal exposures to CO, there were other important exposures to IAP that could potentially affect a pregnant woman. Roughly 80% of the study population were using the temascal, a sauna bath used for hygiene and bathing once or twice a week. Unpublished data from a sub-sample of this population suggest average carbon monoxide exposure levels during temascal use to be 810 ppm-hr/week for women of reproductive age (*12*). The carbon monoxide data presented in this report did not incorporate these significantly elevated sauna bath exposures, which may have contributed to the high incidence of low birth weight among temascal users.

At 22.2%, LBW incidence in the current study is much higher than the national reported incidence. This is most likely to be due to intensive surveillance during the study, which increased the ability to detect LBW and may reflect more accurate data than collected by national statistics. The study's field personnel devised a notification system and arranged for a fieldworker to visit homes to measure birth weight within 48 hours. Twenty-one percent of births in the study remained unmeasured, but as the population is extremely homogeneous, the unknown birth weights were probably similar to the known birth weights. National survey data estimated that 22% of Guatemalan birth weights are unmeasured, and the general population in the region is likely to be similar to the group of women who were monitored during the study women and children who are under-represented and uncounted in the national surveys. Finally, the sample size is too small to detect a significant difference. Despite the limitations, the present results demonstrate a weak, but consistent, relationship between stove type, as a proxy for exposure to CO, and increased LBW among this very vulnerable population.

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2.2 Preliminary analyses of indoor air pollution and low birth weight (LBW) in Southern Pakistan

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Background

More than 21% of infants born in Pakistan are of low birth weight (LBW) or <2500 g (*10*). In the postnatal period, LBW is associated with an increased risk of mortality, morbidity, micronutrient deficiencies, and impaired psychomotor development (*13–15*). The relationship between prenatal exposure to indoor fuel smoke and LBW has not been well studied, although an association of cigarette smoking and outdoor air pollution to increased risk of LBW has been reported in some detail (*16–19*). The leading cause of LBW in developed countries is reported to be maternal smoking as well as exposure to environmental tobacco smoke (*18;19*). The prevalence of active smoking among women is low in Pakistan (20), but the use of wood for cooking fuel is common in rural and urban areas (>53%) and overall biomass use including wood, crop residues, and animal dung is >70% (*21*). In developing country settings, nutritional, reproductive and socioeconomic factors are considered to be the main factors responsible for LBW (*22*). Recent reports from developing countries (Guatemala, Zimbabwe) have described an association between LBW and the use of biomass fuels in open fires for cooking (*5;6*). In addition, analyses from the Second National Family Health Survey of India (1998–99) reported the occurrence of stillbirths related to the use of biomass cooking fuel (*1*). All these studies relied on the use of wood or biomass fuel as a proxy for directly measured exposures to indoor air pollution (IAP). We present the results of preliminary analyses of pregnancy outcomes in relation to cooking fuel use among women in rural, semi-rural and semi-urban communities in Sindh province, southern Pakistan.

Participants and methods

A total of 1404 pregnant women were enrolled through a maternal child health surveillance programme from communities in Nara, Kotdiji and Bilal colonies. Kotdiji and Nara are situated some 400 km from Karachi, while Bilal colony is 50 km from Karachi. Kotdiji has both rural and urban areas, Nara is primarily rural, and Bilal colony is mostly urban. Over 80% of households in Kotdiji, more than 90% in Nara, and about 15% in Bilal colony used wood as the main cooking fuel at the time of the study. Natural gas (NG) was supplied by pipe to registered customers and others who informally shared these points of access. Women who were pregnant in 2000 and 2001 were identified with the help of lady health workers from the government-based National Health Programme. These women were followed up monthly throughout their pregnancy by the study's field workers to determine the outcome of the pregnancy. The outcomes were recorded in a questionnaire and in a log kept at the health centre after verification by field supervisors. Children were weighed on infant scales, and when these were not available the infants were weighed with the mother on a bathroom scale, then subtracting the mother's weight. Gestational age was available for only a few subjects and was therefore not included in the analyses.

Results

Of the total of 1404 pregnant women studied, 8% (n=112) moved out of the study area and 13% (n=182) refused to participate. Reproductive loss through miscarriage occurred in 1.7% and through stillbirth in 7.7% of the 1102 women for whom we had complete follow-ups of pregnancy.

Among the users of wood fuel, 2.4% reported a miscarriage compared to 1.1% among natural gas users (Fig. 1). Stillbirths occurred in 10.2% of pregnant women who used wood compared to 4.8% of NG users (crude OR=2.28, 95%CI=1.34, 3.90). The association of wood use with stillbirth persisted after accounting for the effect of rural-urban location (adjusted OR= 1.90, 95%CI=1.10, 3.20).

Birth weight data were available for 941 women, 53% of whom used wood as cooking fuel during pregnancy. Overall, LBW (<2500 g) was found in 31% of all live births, 38% among infants of mothers who used wood fuel compared to 22% among infants whose mothers used NG (crude OR=2.11, 95%CI=1.57, 2.81).

A composite socioeconomic status (SES) variable was created after assigning scores to individual SES variables including water supply, toilet facilities, lighting source, type

FIG. 1

Comparison of percentages of live births, stillbirths and miscarriages, by type of fuel used in pregnancy

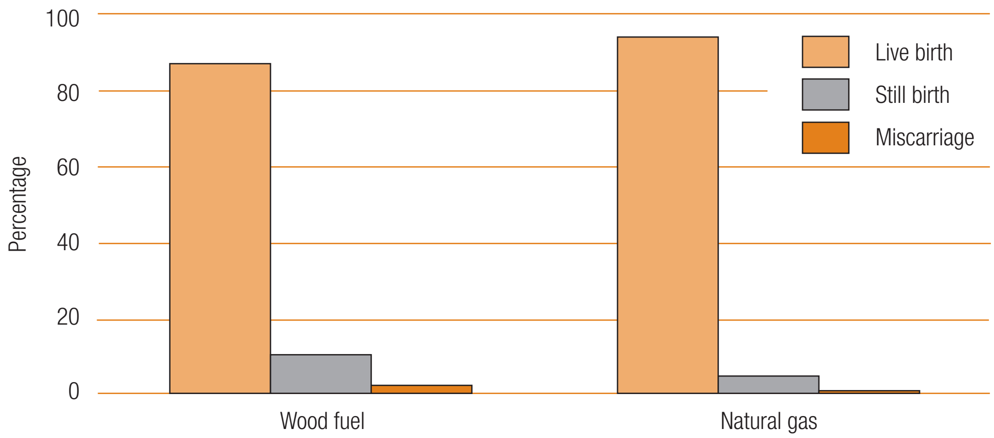

TABLE 1

Results of multiple logistic regression showing odds ratios (95% confidence intervals) for low birth weight in relation to wood fuel versus gas, and other variables included in the analysis

Predictor variable	Comparison	Odds ratio	95% CI
Wood fuel	Natural gas	1.77	1.2 – 2.5
Mother's BMI	Per kg/m^2	0.91	0.87 – 0.95
Gravida status	Per unit	0.93	0.87 – 0.99
Prenatal vaccine	No vaccine	0.42	0.24 – 0.74
SES score ≤ median	SES score > median	1.07	0.73 – 1.55
Rural location	Urban	1.09	0.74 – 1.60

of house construction, house ownership, and housing density (occupants per room), such that a higher socioeconomic status had a high score. A multiple logistic regression model was used to address confounding by the median level of the SES score and other factors: in this analysis, wood fuel was associated with an increased risk of LBW (OR 1.77, 95%CI=1.2-2.5), after adjusting for other variables in Table 1.

Birth weight data were available for 465 out of 641 women who also had blood drawn for serum vitamin A levels (µg/dl). Those who had blood samples drawn did not differ from other study participants by socioeconomic status, rural-urban location, gravida status, and other characteristics. Addition of serum vitamin A levels to the multivariate model above showed an independent effect of increasing vitamin A levels (adjusted OR=0.96, 95%CI=0.95-0.98) per unit (µg/dl) on LBW, while the association of wood fuel use with LBW persisted (adjusted OR=1.78, 95%CI=1.03-3.09).

Indoor air pollution levels

In a separate pilot study, air concentrations for carbon monoxide (CO) and particulate matter (PM) <2.5 microns (PM2.5) were measured in the year 2002 in Bilal Colony (n=9) and the adjoining semi-rural area of Rehri Goth (n=4). Two neighbourhoods in Bilal Colony were selected where wood use was common. In Rehri Goth, two neighbourhoods were selected randomly from a house listing prepared for houses in several blocks. The reference population was stratified by the type of house construction and fuel use. At least one house was randomly selected if more than one house with the same characteristics was present in the same block. An electrochemical monitor with a data logger (IAQ-CALCTM, Model 8762, TSI) was used to measure CO levels. A portable laser photometer (DUSTTRAK™ Aerosol Monitor, Model 8520, TSI) was used to measure PM2.5 continuously in winter. Both monitors stored one-minute average levels in an internal data logger.

CO levels were measured in 13 houses during the summer, and CO and PM2.5 were simultaneously measured in 12 houses during the winter. CO samples during the summer were taken over a minimum period of 24 hours per house, and women performed cooking tasks as usual. During the winter, in the day time, CO and PM2.5 levels were concurrently measured with an average duration of seven hours per house. In summer, the average CO levels were 21.6 ppm in houses using wood for fuel and 3.3 ppm in houses using natural gas (NG). The daytime seven-hour mean CO concentrations ranged from 12.4 to 33.3 ppm in 8 houses using wood and 0.7 to 6.0 ppm in 5 houses using NG. Average 7-hour daytime winter PM2.5 levels were 9.7mg/m^3 for wood use and 0.26 mg/m^3 for NG use. CO and PM2.5 levels did not differ by the type of house construction or season in the given sample setting.

Conclusion

Findings from these preliminary analyses suggest an independent effect of indoor air pollution from open wood fires used for cooking on birth weight and stillbirth. Confounding by rural/urban location and socioeconomic status can be difficult to account for fully, due to the correlation between lower socioeconomic status and use of wood as fuel. Urban and rural areas in this setting differed by the type of cooking fuel, as the majority of households in rural areas used wood. In the presence of inadequate nutrition, increasing gravidity, and poor health care access, the effects of maternal prenatal exposure to indoor air pollution from the use of biomass cooking fuel in Pakistan could be an additional factor for poor obstetric outcomes.

2.3 Maternal exposure to biomass smoke and reduced birth weight in Zimbabwe[1]

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Introduction

Reliance on biomass for cooking and heating exposes many women in developing countries to high levels of many health-damaging air pollutants indoors. Numerous studies have linked exposure to tobacco smoke (both active smoking by mothers and environmental tobacco smoke) and ambient air pollution to intrauterine growth retardation and reduced birth weight, often at pollution levels substantially lower than typically found in biomass-burning homes.

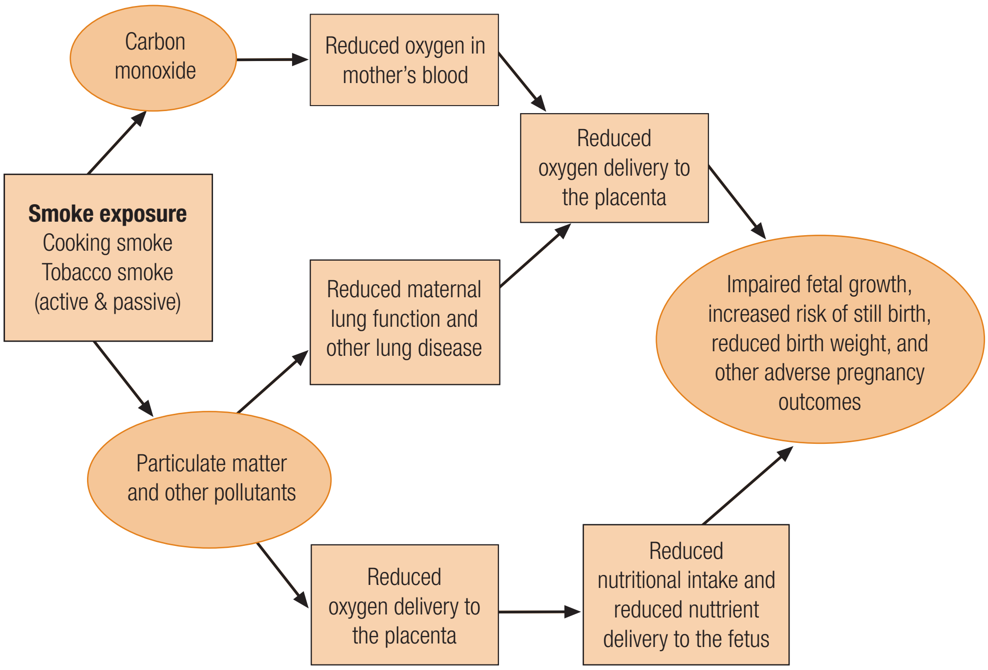
Biomass combustion in simple, inefficient cooking stoves in poorly ventilated conditions causes heavy exposures to CO, which binds to haemoglobin, forms carboxyhaemoglobin, and reduces the oxygen-carrying capacity of blood. A developing fetus, deprived of adequate oxygen, suffers intrauterine growth retardation and an increased risk of reduced birth weight. Particulate matter and other pollutants (e.g. polycyclic aromatic hydrocarbons) in biomass smoke can also increase the risk of intrauterine growth retardation and reduced birth weight by reducing the mother's lung function and increasing the risk of maternal chronic and acute respiratory disease, which also reduces oxygen delivery to the fetus (see Fig. 1).

Although there are good reasons to expect adverse effects of biomass smoke exposure on pregnancy outcomes, only one study, in rural Guatemala, reported an association between biofuel use and reduced birth weight (*5*). In the present study, we examine the association between household use of biomass fuels (wood, dung, or straw) and reduced birth weight using data from a national health survey in Zimbabwe. Data from Zimbabwe provide an excellent opportunity to examine this association because, unlike most developing country situations where a large majority of deliveries take place at home and only a small proportion of children are weighed at birth, three-quarters of the children in Zimbabwe are born in a health facility and are weighed at birth.

[1] The full paper has been published in *Annals of Epidemiology* 2004; 14(10):740–7. For a copy, please contact Vinod Mishra (vinod.mishra@orcmacro.com).

FIG. 1

Possible mechanisms by which exposure to cooking smoke and tobacco smoke might cause adverse pregnancy outcomes. Source: revised from (*1*)



Methods

Analysis in this study is based on information on 3559 childbirths during the five years preceding the 1999 Zimbabwe Demographic and Health Survey. The survey collected demographic, socioeconomic, and health information from a nationally representative probability sample of 6369 households, representing all 10 provinces. The sample is a two-stage cluster sample with an overall response rate of 97.8%. For each birth during the five years preceding the survey, the mother was asked if the child had been weighed at the time of birth. For those weighed at birth, the mother was asked to show the health card, and the birth weight was recorded (in grams) from the card. For mothers who did not have the card, the birth weight was recorded based on the mother's recall.

The survey also asked about the main cooking fuel – wood, dung, straw, charcoal, kerosene, electricity, liquid petroleum gas (LPG)/natural gas, and a residual category of other fuels. Information on fuel types was used to group households into three categories representing the extent of exposure to cooking smoke – high pollution fuels (wood, dung, or straw), medium pollution fuels (kerosene or charcoal), and low pollution fuels (LPG/natural gas or electricity). Households using the medium pollution fuels and the residual category of other fuels (11%) were excluded from the analysis.

A number of generalized linear models were estimated using the SURVEYREG procedure in the SAS System. Control variables included the child's sex and birth order, and the mother's age at childbirth, body mass index (BMI), whether she received iron supplementation or any drug for malaria during the pregnancy, her religion and education in completed years, household standard of living, and region of residence. Because information on pregnancy care (iron supplementation and malaria drugs during pregnancy) was collected only for the last birth in the 5-year period preceding the survey, multivariate analysis was limited only to the last births. The survey found that very few mothers in the sample smoked tobacco (0.7%); information on smoking by other family members was not obtained.

A weighting factor was applied to all observations to compensate for over-sampling of certain categories of respondents in the study design. Results are presented as mean birth weight estimates with significance levels and 95% confidence intervals for categories of each predictor variable by holding other variables constant at their mean values. Estimation of standard errors takes into account design effects due to clustering at the level of the primary sampling unit.

Results

It was found that 78% of all children born during the five years preceding the survey were weighed at birth. Children who were not weighed at birth were considerably more likely to be from households using biomass fuel, compared to those who were weighed at birth (91% and 59%, respectively, using biomass fuel). Health cards were available for 53% of the children who were weighed at birth. For the remaining 47%, the mother reported the birth weight from recall. Children in poorer households and in households using high pollution fuels were slightly more likely to have health cards available at the time of the survey, compared with children in more affluent households and in households using cleaner fuels. Among children weighed at birth, only 8% were of low birth weight (≤2500 g). Slightly more had low birth weight in the biomass fuel households (8.6%) than in the cleaner fuel households (7.7%), a non-significant difference. The mean birth weight of children born in the past five years who were weighed at birth was 3140 g (95%CI: 3119, 3161). Children whose birth weights were based on mother's recall (3174 g) were heavier than those whose birth weights were from health cards (3111 g).

With other factors controlled, babies born to mothers cooking with wood, dung, or straw were 175 g lighter (95%CI: -300, -50), on average, compared with babies born to mothers using LPG, natural gas, or electricity. The difference was 120 g (95%CI: -301, 61) for children whose birth weights were taken from health cards, and 183 g (95%CI: -376, 10) for children whose birth weights were reported by the mothers.

Conclusions

It is notable in this study from Zimbabwe that the proportion of births below 2500 g (8%) is considerably lower and the mean birth weight (3140 g) higher than in many developing countries. The results indicate that household use of high pollution cooking fuels may cause reduced birth weight. Maternal smoking is not likely to be a significant contributing factor because only 0.7% of mothers reported smoking tobacco. The study could not assess the effect of passive smoking because the survey did not collect information on smoking by other family members. The relationship needs to be further investigated using more direct measures of smoke exposure and birth weight and taking account of exposures to passive tobacco smoking. Such research is important because a large proportion of households in Zimbabwe and other developing countries rely on biomass fuels for household energy and low birth weight is a known risk factor for ill health and death in young children.

2.4 Cooking fuel and tobacco smoke as risk factors for stillbirth[1]

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Introduction

Numerous studies have linked tobacco smoke (both active smoking by the mother and environmental tobacco smoke) and ambient air pollution to adverse pregnancy outcomes. Although smoke from biomass combustion produces some of the same pollutants found in tobacco smoke and ambient air, only one study has linked cooking with biomass fuels during pregnancy to stillbirths (*23*), and two recent studies, in Zimbabwe and in rural Guatemala, have linked it to reduced birth weight (*5;6*). This study examines the association between household use of biomass fuels (wood, dung, or crop residues), tobacco smoking (both active and passive) and the risk of stillbirth using data from a large national family health survey in India.

The primary mechanism by which biomass smoke may cause stillbirth is through exposure to carbon monoxide (CO). As in the case of tobacco smoke, biomass combustion in simple, poorly vented cooking stoves produces large volumes of CO, which binds to haemoglobin and forms carboxyhaemoglobin. This reduces the capacity of the blood to carry oxygen to the body tissues. A developing fetus, deprived of adequate oxygen, suffers intrauterine growth retardation and increased risk of perinatal mortality. Particulate matter and other pollutants (e.g. polycyclic aromatic hydrocarbons) in biomass smoke can also increase the risk of an adverse pregnancy outcome by reducing the mother's lung function and increasing the risk of maternal chronic and acute respiratory disease, which also reduces oxygen delivery to the fetus.

Methods

Data are from the 1998–99 Indian National Family Health Survey, which collected demographic, socioeconomic and health information from a nationally representative probability sample of 92 486 households. All states of India are represented in the sample, covering more than 99% of the country's population. The sample is a multi-stage cluster sample with an overall response rate of 98%. The survey collected complete birth histories, including information on stillbirths, from all 90,303 ever-married women aged 15–49 years included in the survey. Separate questions were asked about induced abortion and spontaneous abortion (i.e. miscarriage or delivery of a dead baby before 28 weeks). In order to minimize recall lapse, the women were asked about stillbirths separately for each birth interval (including open birth intervals at both ends). The principal analysis in this study is based on 19,189 ever-married women aged 40–49 with completed birth histories.

The survey also collected information on primary and secondary fuels used for cooking or heating, using a ten-fold classification of fuels – wood, crop residues, dung cakes, coal/coke/lignite, charcoal, kerosene, electricity, liquid petroleum gas, biogas, and a residual category of other fuels. This information on cooking and heating fuels is used to categorize the extent of exposure to cooking smoke – high exposure (households using only biomass fuels: wood, crop residues, or dung cakes), low exposure (households using only cleaner fuels: kerosene, petroleum gas, biogas, or electricity), or medium exposure (a mix of biomass fuels and cleaner fuels or coal/coke/lignite/charcoal).

[1] The full paper has been published in the *International Journal of Environmental Health Research*; 15(6):397–410. For a copy, please write to Vinod Mishra (vinod.mishra@orcmacro.com).

The information on current and lifetime tobacco smoking by the mother and other household members is used to categorize the extent of exposure to tobacco smoke – active smoking (mother currently smokes or has smoked regularly in the past), passive smoking (one or more other persons in the household smoke currently), no smoking (mother has never smoked regularly and no other person in the household smokes currently).

We estimated the effects of cooking smoke, measured by type of cooking fuel, and tobacco smoke (both active and passive) on the likelihood of having a stillbirth, using binary and multinomial logistic regression after controlling for a number of potentially confounding factors, including mother's anaemia status, body mass index, education, religion of household head, caste/tribe of household head, house type, availability of a separate kitchen in the house, crowding in the household, living standard of the household, urban/rural residence, and geographic region. Estimation of the effects of cooking smoke and tobacco smoke on the likelihood of having a stillbirth takes into account sampling weights and design effects due to clustering at the level of the primary sampling unit.

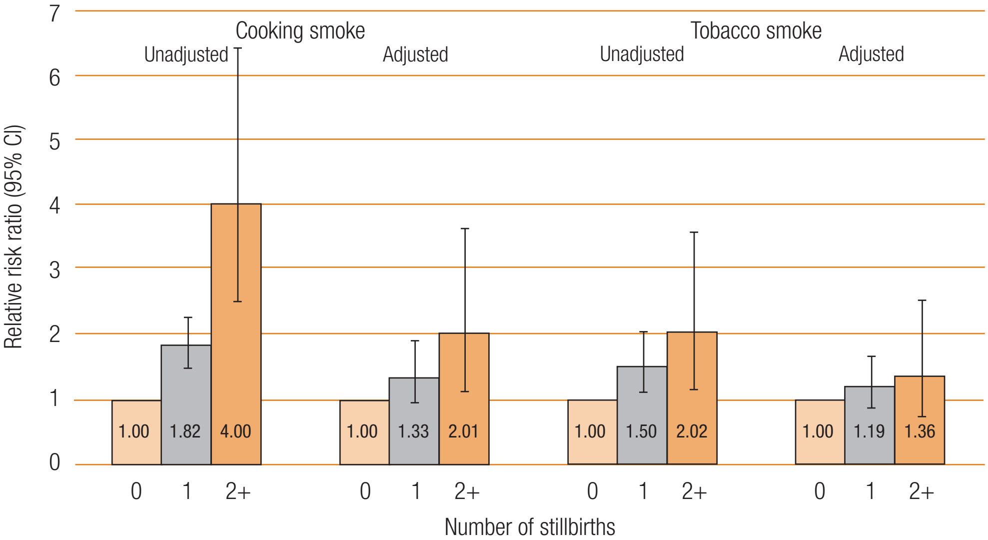
Results

A majority (53%) of ever-married women aged 40–49 years cooked with high-pollution biomass fuels, and another 27% used biomass fuels in combination with cleaner cooking fuels. Fewer women (5%) smoked tobacco or had ever smoked tobacco regularly in the past, but a considerable proportion of women (42%) lived in households with other active smokers; 7% of ever-married women aged 40–49 years reported having experienced a stillbirth in their lifetime.

With other factors controlled, the women who cooked only with wood, dung, or crop residues were significantly more likely to have experienced a stillbirth than those who cook with electricity, LPG, biogas, or kerosene (OR=1.44; 95%CI: 1.04, 1.97). The results also indicate that women who cooked only with biomass fuels were twice as likely to have experienced two or more stillbirths as those who cooked with cleaner fuels (RRR=2.01; 95%CI: 1.11, 3.62) – see Fig. 1. The adjusted effect of active tobacco smoking on the risk of stillbirth is also positive (OR=1.23) but not statistically significant. No

FIG. 1

Unadjusted and adjusted effects of cooking smoke (biomass fuels relative to cleaner fuels) and tobacco smoke (active smoking relative to no smoking) on the relative risk of 0, 1 and 2+ stillbirths (risk relative to no stillbirth) in India 1998–1999. Source: Mishra V et al 2005



effect of passive smoking was found, nor was there evidence of any modifying effects of active or passive tobacco smoking.

We repeated the above analysis for a larger group of women aged 20–49 years (n=78 660) included in the survey, after additionally controlling for the woman's age and age-squared. We found that the effects of cooking smoke on the risk of stillbirth in women aged 20–49 were similar to those observed for women with completed birth histories (aged 40–49). We also tested for interactions between the effects of cooking smoke and tobacco smoke in the larger group of women, but found no modifying effects of tobacco smoke exposure.

Conclusions

The results indicate that cooking with high-pollution unprocessed biomass fuels may increase the risk of stillbirth. Further research with more direct measures of smoke exposure and clinical measures of pregnancy outcomes is needed to validate these findings.

2.5 Particulate matter air pollution and perinatal outcomes

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Background

An increasing number of studies have evaluated the relationship between particulate matter air pollution and perinatal health (*24;25*). Studies have found suggestive evidence of the effects of particulate matter air pollution on LBW (*7;26;27*), pre-term delivery (*28;29*), and relatively strong evidence for post-neonatal respiratory infant mortality (*30–35*).

While the evidence suggests that outdoor particulate matter air pollution can affect perinatal outcomes, some questions remain. Important questions for future research include: further assessing the association between particulate matter air pollution and perinatal outcomes, focusing on the potential role of $PM_{2.5}$; exploring whether there are critical windows of exposure that are most associated with low birth weight and pre-term birth; and assessing whether other measurements of exposure may be more amenable to evaluating relationships.

Findings of outdoor air pollution and its effects on perinatal health are particularly relevant in developing countries where women experience exposure to much higher levels of particulate matter through use of solid fuels in the home.

We have conducted a series of analyses in California, USA, using a unique dataset linking maternal addresses to $PM_{2.5}$ and CO monitors within 5 miles to evaluate the relationship between $PM_{2.5}$ and several perinatal outcomes: birth weight, pre-term delivery, and post-neonatal infant mortality for births in 1999–2000.

[1] This article represents the views of the authors and not necessarily those of U.S. EPA or CDC.

Low birth weight in California

We matched $PM_{2.5}$ and carbon monoxide (CO) data from air pollution monitors to birth records for singleton births delivered at 40 weeks gestation. Exposure was based on pollution measurements averaged over the duration of pregnancy and for each trimester. Using logistic regression and adjusting for maternal demographic factors, we found an adjusted odds ratio for small-for-gestational age (SGA) for exposures in the highest compared to lowest quartile of $PM_{2.5}$ of 1.26 (95% CI: 1.03 to 1.50). We found no association between CO and birth weight or SGA after controlling for maternal factors and $PM_{2.5}$ (mean birth weight difference, 2.6 g, 95% CI: -20.6 to 25.8). The difference in mean birth weight for infants with a 9-month exposure in the highest quartile of $PM_{2.5}$, compared to that of infants exposed in the lowest quartile, was -36.1 g (95%CI: -16.5 g to -55.8); this difference was similar after controlling for CO. The findings were similar by trimester of exposure.

Pre-term birth

For this analysis, we used a matched case-control design. $PM_{2.5}$ and CO monitoring data were linked to California birth certificate data for singletons. County level CO measures were used to increase the sample size and maintain a representative population. Each of the 10 673 pre-term cases was matched to 3 controls of term (39–44 week) gestation with a similar date of last menstrual period. Based on the case's gestational age, CO and $PM_{2.5}$ exposures were calculated for total pregnancy, first month of pregnancy, and last two weeks of pregnancy. Due to the matched design, conditional logistic regression was used to adjust for maternal race/ethnicity, age, parity, marital status, and education. High $PM_{2.5}$ exposure during the entire pregnancy was associated with a small effect on pre-term birth, after adjustment for maternal factors (adjusted OR=1.15, [1.07, 1.24]). The OR did not change after adjustment for CO. Results were similar for $PM_{2.5}$ exposure during the first month of pregnancy (adjusted OR=1.21, [1.12, 1.30]) and the last 2 weeks of pregnancy (AOR=1.17, [1.09, 1.27]). Conversely, CO exposure at any time during pregnancy was not associated with pre-term birth (adjusted ORs from 0.95 to 1.00).

Post-neonatal infant mortality

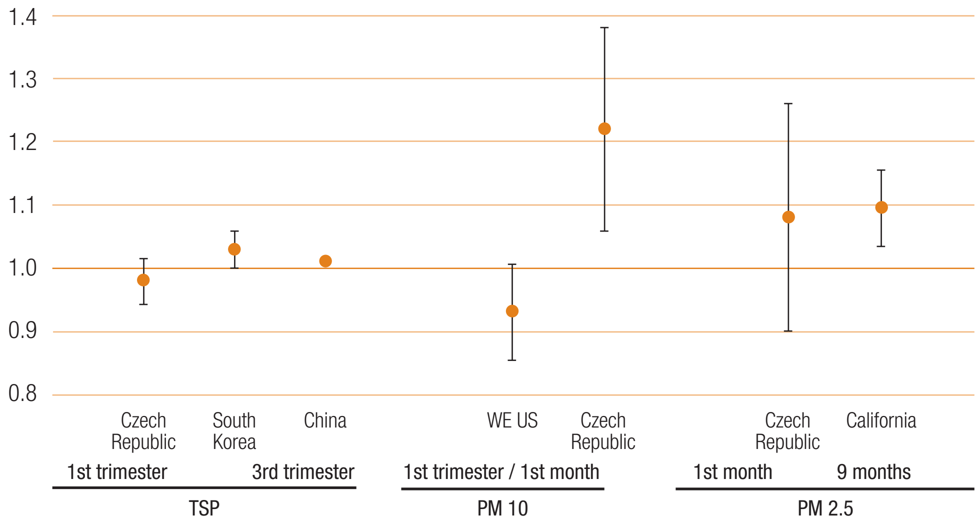
In this analysis, we matched each postneonatal infant death to 4 infants surviving to one year of age, by birth weight and date of birth (within 2 weeks). For each matched set, we calculated exposure as the average $PM_{2.5}$ concentration over the period of life for the infant who died. We used conditional logistic regression to estimate the odds of post-neonatal all-cause, respiratory-related, Sudden Infant Death Syndrome (SIDS), and external causes (a control category) mortality by exposure to $PM_{2.5}$, controlling for the matched sets and maternal demographic factors. We matched 788 post-neonatal infant deaths to 3089 infant survivors. There were 51 post-neonatal deaths due to respiratory causes and 120 post-neonatal deaths due to SIDS. We found an adjusted odds ratio for a 10 $\mu g/m^3$ increase in $PM_{2.5}$ of 1.07 (95%CI: 0.93–1.24) for overall postneonatal mortality, 2.13 (95%CI: 1.12-4.05) for respiratory-related postneonatal mortality, 0.82 (95%CI: 0.55–1.23) for SIDS, and 0.83 (95%CI: 0.50–1.39) for external causes.

Summary

In California, we found a relationship between $PM_{2.5}$ and each of the perinatal outcomes evaluated. In addition, we did not identify any particular window of susceptibility for low birth weight or pre-term birth. These analyses should be evaluated in conjunction with the growing literature on perinatal effects and PM (particulate matter) and other

FIG. 1

Adjusted odds ratios for particulate matter and measures of intra-uterine growth retardation from selected studies (*7;8;26;27;36;37*)



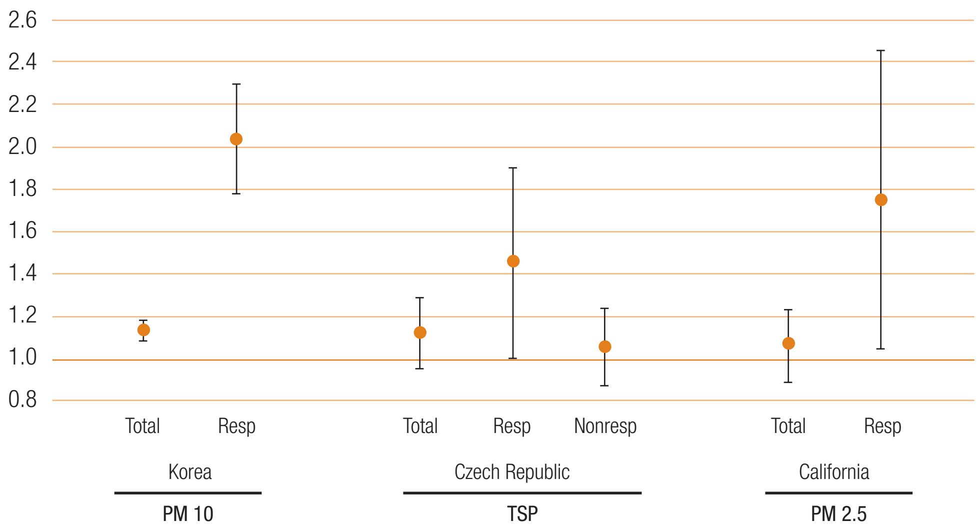
* Note the increment for PM2.5 is 5 µg/m³

air pollutants. Fig. 1 shows the adjusted ORs from different locations around the world for different measurements of growth retardation, with the adjusted ORs for the exposure window with the highest association. As the variability in response may be due to differences in the composition of the particulate matter in different geographic locations or slight differences in study design, further research is warranted. The evidence suggests an effect of particulate matter air pollution on birth weight, though there is potential for geographic variation in the relationships and it is unclear if there is a particular exposure window of importance. Fig. 2 presents the results for some of the studies on infant mortality, showing fairly consistent associations for respiratory-related mortality.

While research remains to refine the exact nature of these relationships, prudent public policy suggests that protection again potential perinatal effects is another reason to focus on reductions in air pollution levels.

FIG. 2

Adjusted odds ratios for particulate matter and post-neonatal infant mortality from selected studies for an inter-quartile range increase in particulate matter (*30;32;35*)



3 Summary of evidence

Method and search strategy

Tables 3.1 and 3.2 (see below) summarize the findings from developing countries which were presented at the symposium. To identify published studies that were not known to the authors, a preliminary additional search of PubMed was carried out by N.B. and D.P. using the following terms.

Exposure terms	Outcome terms
• Chula (chulla, chullah) • Cooking fire • Smokeless stove, Improved stove • Indoor smoke • Indoor air pollution • Wood fuel, biomass, solid fuel	• Birth weight • Gestational age, gestation • Intrauterine growth retardation • Neonatal mortality • Perinatal mortality • Stillbirth • Premature birth, premature • Pre term, preterm, pre-term

Combining the exposure and outcome terms yielded 190 studies, 44 of which were retained as relevant for review of their abstracts. Only one new report relevant to the current topic was found (*38*), and this has been included in Table 3.1.

The information in Tables 3.1 and 3.2 was compiled from the symposium papers and published articles by N.B., who could contact the symposium papers' authors for clarification.

Synthesis and conclusions

A brief overview and synthesis of the results are given in this section, without a systematic review of methodology, publication bias or heterogeneity although some comments are made on these issues.

In respect of publication bias, while only a preliminary search was made at this stage using PubMed (see above), the matter was discussed before the symposium with researchers active in this field, and we are not aware of any other ongoing or unpublished studies. Efforts will be made to identify studies and assess publication bias in the next stage of this work.

We have not yet carried out hypothesis testing for heterogeneity, but there appears to be little evidence of this for either LBW or stillbirth outcomes, based on the observation that there is no overlap in the 95% confidence intervals for the available estimates.

Some additional comments on methodological issues are presented in the following two sections which summarize the results for LBW and stillbirth.

Low birth weight

Five studies are included: one survey, two cohorts, one case-control and one randomized controlled trial. One was hospital-based (*38*) and four were mainly community studies or mixed (*5*).

Differences in exposure were expressed as biomass vs. clean fuel for four studies, and biomass in open fires vs. ventilated stoves in one study (Thompson 2006).[1] Direct exposure measurements were available in the latter although exposure-response relationships have not yet been analysed, and in a small sub-sample of homes for another study (Siddiqui 2006).

Measurement of birth weights was variable owing to difficulties in obtaining accurate data on all births within 1–2 days in poor countries where the majority of births occur at home without trained staff who measure and record birth weights routinely for all deliveries. The assessment of gestational age presents similar (probably greater) challenges and was available in only two of the five studies.

Results are presented (or are potentially available) in two ways: (a) as differences in mean birth weights for exposed and non-exposed persons, and (b) as differences in the percentage of deliveries that are low birth weight (<2500 g). The prevalence of LBW varied markedly from 8% in Zimbabwe (*6*) to over 30% in Pakistan (Siddiqui 2006).

For mean birth weight, the differences for 'high' vs. 'low' exposures in four studies ranged from 50 to 175 g lower weight with the higher exposure. Three of the studies showed statistically significant differences. For percentage LBW, odds ratios for high exposure vs. low exposure – available currently from two studies – were 1.74 and 1.16, one of which (1.74) was statistically significant. One study found significant ORs (P <0.05) for term LBW (1.20) and pre-term LBW (1.50) (*38*), but only in the unadjusted results, and it is assumed these became non-significant in multivariate analysis; however, it is not clear what effect the selection of cases and controls (in particular, the inclusion of all LBW babies dying in the perinatal period in the case series – see Table 3.1) might have on the interpretation of the findings of this study.

Stillbirth

Three studies are included: one case control, one survey, and one cohort (Table 3.2). One was hospital-based, the other two were community samples. Two obtained information on stillbirths from health records and interviews carried out as part of a prospective study (*23*, Siddiqui 2006), the other relied on recall at interview (*1*).

For all three studies, differences in exposure were expressed as biomass vs. cleaner fuel, with one study measuring pollution and exposures in a small sub-sample of homes (Siddiqui 2006).

All three studies adjusted results for confounding. Adjusted odds ratios for high exposure vs. low exposure ranged from 1.44 to 1.90, and all three were statistically significant although the result reported by Mavalankar et al was very close to the 5% significance level (*23*). The report of the large Indian survey by Mishra et al additionally

[1] Studies referred to by author's name in parenthesis, e.g. (Thompson 2006), are the *unpublished* work presented at ISEE in 2005 and reported in more detail (with some additional analysis and interpretation) in this publication in the relevant chapter and in Tables 3.1 and/or 3.2.

found an adjusted risk ratio of 2.01 (1.11, 3.62) for two or more stillbirths compared to zero stillbirths (*1*).

Ambient air pollution studies

Evidence from ambient pollution studies carried out in California, USA (not included in Tables 3.1 and 3.2) shows an effect of PM2.5 on birth weight (25% increased risk, and mean difference of 36 g for the lowest vs. the highest exposure groups. No independent effect of CO on birth weight was found. A small effect of $PM_{2.5}$ (15% increase in risk) was also found for pre-term birth, with again no effect of CO exposure. $PM_{2.5}$ was also found to increase the risk of respiratory causes of post-neonatal mortality.

Conclusion

Presented here is an overview of a relatively small number of studies on the effects of indoor air pollution (IAP) on LBW and stillbirth in developing countries. Among the limitations of this evidence, apart from the small number of studies, is that exposure differentials were mainly expressed in terms of use of biomass compared to cleaner fuels, although this is supported by some direct exposure measurements in two of the studies. Another issue is the variation in birth weight and gestational age assessment resulting from the practical difficulties involved in making accurate and timely measurements in poor, isolated communities with low service provision and use. Finally, it must be acknowledged that this report is a preliminary summary, and not the product of a full systematic review.

Accepting these limitations, this initial review and synthesis suggest important and fairly consistent effects of IAP on both LBW and stillbirth. If confirmed, these findings will have important public health consequences because of the very large number of women of child-bearing age who live in poor countries where adverse pregnancy outcomes are already highly prevalent and who experience high levels of IAP exposure on a daily basis throughout pregnancy.

Although there are likely to be differences in component pollutants between developed country ambient air pollution and developing country indoor air pollution, with much lower levels of exposure in the former, the findings from these studies of ambient air pollution will play an important part in our understanding of the possible effects of IAP from solid fuels in the world's poorest countries.

Taken together, the findings of this review make a strong case for (a) a systematic review – and if appropriate a meta-analysis – of all studies on indoor air pollution and pregnancy outcomes that can be identified, and (b) further epidemiological field studies addressing the limitations identified to date in exposure measurement and outcome assessment.

TABLE 3.1

Summary of studies on risk of low birth weight associated with solid fuel use

Location	Author and date (year)	Study design and outcome measurement	Numbers of subjects	Exposure comparison	Adjustment for confounding	Effect	Estimate (95% CI)	p-value
Guatemala	Boy 2002 [paper not included in ISEE 2005 symposium]	Cross-sectional survey. Birth weight measured to nearest 50 g by trained staff as soon as possible after birth, but within 72 hours. Singleton births only. Gestational age by LMP and method of Capurro.	871 (open fire, no chimney); 289 (stove with chimney); 357 (electricity or LPG)	Wood in open fires and improved wood stoves vs. cleaner cooking fuels (LPG and electricity). Measurements of IAP and exposure not available.	Adjustment for parity; gestational age <37 weeks; mother's age; floor material (SES proxy); urban or rural residence; vitamins in 3rd trimester; mother's calf circumference.	Mean weight	Adjusted: 63 g (0.4, 126)	0.049
						% LBW	Unadjusted: Open fire: 19.9% Stove: 16.8% Clean fuel: 16.0%	Overall: 0.2 Trend: 0.08
Guatemala	Thompson (in preparation)	Randomized controlled trial. Birth weight measured by trained staff as soon as possible after birth (up to 7 days). Singleton live births only. Gestational age not assessed.	105 with open fire; 120 with *plancha* chimney stove	Traditional open fire (wood) vs. *plancha* chimney wood stove. Mean 48-hour CO exposure of pregnant women: 2.49 ppm (open fire); 1.97 ppm randomization (*plancha*), a 20% difference (p <0.05)	Adjusted for mother's age, primiparity, > 5 births, socioeconomic conditions, father smoking. Based on *plancha*	Mean weight	60 g (-55, 176)	0.30
Zimbabwe	Mishra 2004	Cross-sectional survey (DHS), a nationally representative sample, of birth in prior 5 years. Birth weight recorded from health card, or if not available, as recalled by the mother. In Zimbabwe, 75% of births take place in a health facility and are weighed. Gestational age not available.	2610 singleton births; 1390 with weight on health card, 1220 by mother's recall	Comparison of high pollution homes (wood, dung, straw) vs. cleaner fuels (LPG, natural gas, electricity). IAP and exposure not measured.	Adjusted for sex of child; birth order; mother's age; mother's BMI; iron supplement in pregnancy; drug for malaria in pregnancy; mother's education (years); religion; household standard of living; region of residence.	Mean weight	All: 175 (50, 300) Cards: 120 (-61, 301)	0.006 NS
						% LBW and odds ratio for biomass vs. clean fuel	All: biomass 8.6%, clean fuel 7.7%	NS

TABLE 3.1 *Continued*

Location	Author and date (year)	Study design and outcome measurement	Numbers of subjects	Exposure comparison	Adjustment for confounding	Effect	Estimate (95% CI)	p-value
Pakistan	Siddiqui (in preparation)	Cohort study. Birth weight measured by trained staff within 48 hours of delivery in the majority of cases. Singleton live births only included. Gestational age data were incomplete and therefore not included in analyses	Birth weight available on 941 births. 53% of sample used wood fuel	Biomass (mainly wood) in open fire vs. piped natural gas. Separate study found mean (7-hour) $PM_{2.5}$ of 9.7 mg/m^3 (wood) and 0.26 mg/m^3 (gas)	Adjustment for BMI; parity; prenatal vaccination tetanus); SES score; rural vs. urban residence.	Mean weight (wood vs. gas)	96 (15, 176)	0.02
						Odds ratio for wood vs. gas	Unadjusted (%): 38.2% (wood), 22.7 (gas) Adjusted OR: 1.77 (1.2, 2.5)	<0.01
					Vitamin A in sub-sample analysis	Odds ratio for wood vs. gas	Adjusted: 1.78 (1.03, 3.09)	<0.05
India	Mavalankar 1992	Case control study of births in government teaching hospitals in Ahmedabad city, with a population survey to estimate prevalence of risk factors in sections of population delivering at home and in government and private hospitals. Birth weight and gestational age (by LMP and method of Capurro)	1317 cases (systematic sample of 20% of surviving LBW births, and all LBW dying in perinatal period). 1465 controls >2.5 kg surviving to discharge or up to 7 days.	Exposed vs. not exposed to cooking smoke, from response to interview in case-control study. 30% of control women were exposed to cooking smoke	Adjusted for wide range of factors including; mother's age; prior obstetric history; weight, anaemia; antenatal care; various intra-partum complications; referral, maternal occupation; use of tobacco	OR for term LBW	Unadjusted: 1.2 (95% CI n/a) Adjusted: Not provided	<0.05 NS
						OR for pre-term LBW	Unadjusted: 1.5 (95% CI n/a) Adjusted: Not provided	<0.05 NS

TABLE 3.2

Summary of studies on risk of stillbirth associated with solid fuel use

Location	Author and date (year)	Study design and outcome measurement	Numbers of subjects	Exposure comparison	Adjustment for confounding	Effect estimate (OR and 95% CI)	p-value
India	Mavalankar 1991	Case control study of births in government teaching hospitals in Ahmedabad city, with a population survey to estimate prevalence of risk factors in sections of population delivering at home and in government and private hospitals.	451 stillbirths, 160 early neonatal deaths, 1465 controls (all above 2500 g).	Exposed vs. not exposed to cooking smoke, from response to interview in case-control study. 30% of control women were exposed to cooking smoke	Adjusted for wide range of factors including mother's age; prior obstetric history; weight, anaemia; antenatal care; various intra-partum complications; referral, maternal occupation; use of tobacco	Exposed vs. not exposed OR = 1.5 (1.0, 2.1)	0.05
India	Mishra 2005	Second Indian National Family Health Survey (1998–99), a multi-stage nationally representative sample with response rate by women of 96%. Stillbirth defined as delivery of dead baby after 28th week of pregnancy.	19 189 ever-married women aged 40–49 with complete birth histories.	Using question on fuel types used for cooking and heating, classified into three groups: ***high*** exposure (wood, dung and crops); ***medium*** (mix of biomass, cleaner fuels, coal, etc.); and ***low*** (LPG, electricity, kerosene, natural gas). No direct measurement of IAP or exposure.	A range of models are presented with varying degrees of adjustment, from just tobacco smoking, through to a full model adjusting for tobacco smoking, anaemia, BMI, education, caste and religion, house and kitchen type, crowding, standard of living, urban/rural residence, and region of the country.	Full adjustment model for high exposure vs. cleaner fuels: 1.44 (1.04, 1.97) RRR for 2 or more stillbirths = 2.01 (1.11, 3.62)	<0.01 <0.01
Pakistan	Siddiqui (in preparation)	Cohort study. Singleton births only	Birth weight available on 941 births. 53% of sample used wood fuel.	Biomass (mainly wood) in open fire vs. piped natural gas. Separate study found mean (7-hour) $PM_{2.5}$ of 9.7 mg/m^3 (wood) and 0.26 mg/m^3 (gas)	Adjustment for rural vs. urban residence only.	Unadjusted: 2.28 (1.34, 3.90) Adjusted: 1.90 (1.10, 3.20)	<0.001 <0.01

4 Further research needs

A workshop, held after the symposium, reviewed the evidence presented and discussed further research needs and how this might be promoted.

Consensus on evidence

There was consensus that the evidence presented on indoor and outdoor air pollution, together with that from environmental tobacco smoke, made a strong case for an important impact of IAP on (i) low birth weight and (ii) stillbirth, and that priority should be given for further research to confirm and quantify these effects.

Key health outcomes for future studies

The following outcomes should be considered for inclusion in future studies:

Priority outcomes

- Birth weight
- Stillbirth
- Spontaneous abortion
- Pre-term delivery (including assessment of gestational age to distinguish between pre-term delivery and intrauterine growth retardation)
- Perinatal mortality
- Perinatal morbidity (specific causes).

Other outcomes

- Birth defects
- Haemoglobin levels in newborns
- Measures of post-natal growth.

Exposure assessment issues

The following are important:

- Assessment of exposures of the fetus during each trimester, as a means of studying (i) the direct effects of maternal exposures during pregnancy, and (ii) the stages that are most critical in respect of the various outcomes (3.2).

- Assessment of lifetime exposures of the mother, as a means of studying the indirect effect of the mother's health on the developing fetus.

Study design options and opportunities

The following options were considered worth pursuing.

- Extension of routine survey-based data sources such as DHS, as employed by Mishra et al (*1;6*), despite some limitations – in particular, the absence of reliable data on birth weights and stillbirths in many of the populations at highest risk of (a) exposure and (b) outcomes. However, household surveys, such as the DHS, are based on a sampling frame that is representative at both national and sub-national levels. Provided additional funding is available, this sampling frame can be used to add more study components, such as indoor air pollution exposure monitoring or the use of specific biomarkers, or to identify pregnant women for a cohort study on birth outcomes.
- Prospective case-control studies to allow assessment of exposures. This design is dependent on the ability to obtain reliable data on birth weights and vital events monitoring to identify cases; exposure assessments carried out retrospectively may be open to (probably minimal) bias.
- Cohort studies, such as that reported here by Siddiqui et al appear to have considerable potential, particularly where substantial proportions of biomass and clean fuel users can be identified within socioeconomic strata. Opportunities may be provided by WHO longitudinal studies on reproductive health, which should provide the main infrastructure for high quality data on pregnancy and birth outcomes.
- Intervention studies, if randomized, should overcome confounding, but will be the most expensive and complex option.

Potential funding sources

Funding for feasibility assessment and protocol development may be available from sources such as WHO (possibly via USAID and others) and UNICEF. Funding for the main study could be sought from the Medical Research Council (UK), The Wellcome Trust, NIEHS, etc.

Next steps

On completion of this report, discussions are planned with donors who might support the development of further studies. The report will be circulated to the participants and will also be on the websites of WHO's Department of Child and Adolescent Health and Development (CAH) and Department of Public Health and Environment (PHE). A start to develop the study proposals will be made at a forthcoming meeting, or through WHO.

A systematic review of the studies will be carried out to ensure that no important information has been overlooked. For as long as sufficient, comparable evidence is found, meta-analyses for (a) birth weight and (b) stillbirths will be conducted. This work will be reported in a separate publication.

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