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gSCIENCE

ORIGINAL RESEARCH

Adult Cardiopulmonary Mortality and Indoor Air Pollution

A 10-Year Retrospective Cohort Study in a Low-Income Rural Setting

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BACKGROUND Indoor air pollution (IAP) due to solid fuel use is a major risk factor of respiratory and cardiovascular mortality and morbidity. Rural Matlab in Bangladesh has been partly supplied with natural gas since the early 1990s, which offered a natural experiment to investigate the long-term impact of IAP on cardiopulmonary mortality.

OBJECTIVE This study sought to compare adult cardiopulmonary mortality in relation to household fuel type as a surrogate for exposure to indoor air pollution.

STUDY DESIGN This was a retrospective cohort study. We identified all households in 11 villages in Matlab, Bangladesh, and categorized them as either supplied with natural gas or using solid fuel for cooking or heating since January 1, 2001. Cause-specific mortality data including cardiopulmonary deaths were obtained through verbal autopsy as part of a permanent surveillance. Person-years (PYs) of exposure were computed from baseline until the event. Subjects with missing information on cause of death, outward migration, or on fuel type were excluded. Event rates for each fuel category were calculated as well as the relative risk of dying with 95% confidence intervals (CI).

SETTING Rural Matlab, Bangladesh.

PATIENTS Adults 18 years of age or older.

OUTCOME MEASURE Death from cardiopulmonary diseases over a 10-year period.

FINDINGS In total, 946 cardiopulmonary deaths occurred with 884 in the solid-fuel and 62 in the gas-supplied households (n = 7,565 and n = 508, respectively) over the 10-year period. Cardiopulmonary death rate was 6.2 per 1,000 PYs in the solid-fuel group and 5.3 per 1,000 PYs in people living in households using gas. Mortality due to cardiovascular event was 5.1 and 4.8 per 1,000 PY in people from the solid-fuel and gas-supplied households, respectively, and the incident rate ratio was 1.07 (95% CI: 0.82 to 1.41). Mortality due to respiratory disease was 1.2 and 0.5 per 1,000 PYs in the solid-fuel and gas-supplied groups, respectively, and the incident rate ratio was 2.26 (95% CI: 1.02 to 4.99).

INTERPRETATION Household solid-fuel use is associated with increased respiratory mortality and nonsignificantly increased risk of cardiovascular mortality. Reduction of exposure to pollution due to in-household solid-fuel use is likely to improve survival in Bangladeshi and similar populations.

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Indoor air pollution (IAP) due to solid-fuel use is the second biggest risk factor for ill heath and is accountable for 2 million deaths annually and 2.7 percent global burden of disease [1]. In 2002, an estimated 46,000 deaths in children under five years and among adults 30 years or older, and 3.6% of national disease burden was attributable to IAP due to solid-fuel use in Bangladesh. IAP exposure due to solid-fuel use reported to be associated 2.35× greater mortality due to acute lower respiratory infection in young children [2] and greater mortality in adults due to chronic obstructive pulmonary disease [3]. More recent research has revealed that IAP exposure has greater deleterious effect on cardiovascular mortality and morbidity [4–6]. Therefore, the burden of disease due to IAP estimated based primarily on respiratory morbidity and mortality is considered grossly underestimated particularly in economically less-developed countries where nearly three-quarters of people still use solid fuel for cooking and heating.

Data from Bangladesh showed burning biomass fuel (e.g., wood, cow dung, crop residue) produce high concentrations of particulate matter in and around the cooking areas including the living rooms [7]. Over 80% of the Bangladesh population depends on solid fuel for household cooking and heating. Although high-level IAP due to solid-fuel burning in traditional cook stoves is well documented in Bangladesh, its long-term impact on adult cardiopulmonary mortality is not known.

A longitudinal study to assess the long-term health impact of IAP will require long-term follow-up of large population with or without clean fuel supply and cause-specific mortality data. Such prospective study is likely to be very expensive and practically challenging. Some rural areas in Bangladesh have been partially supplied with natural gas, which creates a natural experiment and provides an opportunity to investigate long-term impact of high versus low exposure to IAP provided high-quality cause of death data are available.

We evaluated a natural experiment of long-term exposure to solid fuel or natural gas use for household cooking and the incidence of cardiopulmonary mortality over a 10-year (2001 to 2010) period in a retrospective cohort in a rural area in Bangladesh.

SUBJECTS AND METHODS

Study design and population. This retrospective cohort study was based on 10-year data (2001 to 2010) available for 11 villages in rural Matlab, Chandpur, Bangladesh. These villages were chosen purposively as they have piped natural gas (clean fuel) supply in part of the village since the early 1990s and the rest rely on solid fuel. As the villages have households with or without gas supply, this offered a natural experiment to compare cardiopulmonary mortality between households with 2 different fuel types used as a surrogate for the high and low IAP. Solid fuel is highly polluting when burnt in open fire or traditional cook stoves, which is the practice in those villages [7].

The study population was adults (≥ 18 years) who were residents of those villages as of January 1, 2000. The study villages are within a Health and Demographic Surveillance System (HDSS) area of International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b), which has been maintained in Matlab since 1963 [8], which currently covers 210,000 populations in 142 villages. Precise demographic data are available for each individual living within the HDSS area, which is regularly updated in a computerized database. All deaths among adult permanent residents of those villages that occurred between January 1, 2001, and December 31, 2010, with specific cause were obtained from the HDSS database. We verified each death and fuel type of the household of the deceased person through household visit.

Exposure ascertainment. We used fuel type as the exposure surrogate. We ascertained household fuel type—solid fuel or natural gas—used for cooking or heating, as of January 1, 2001, confirmed by home visit and examination of the related documents or bill payment statement. Every adult individual was then assigned an exposure code by fuel type. Individuals belonging to households using solid fuel at the beginning (January 1, 2001) but who received gas supply sometime during the study period were excluded. However, such households constituted less than 2% of the total households.

Cause of death data. We collected causes of all deaths that occurred between January 1, 2001, and December 31, 2010, in the 11 study villages from the verbal autopsy database of the HDSS of icddr,b [8]. The HDSS uses a validated verbal autopsy method that was developed by icddr,b in collaboration with the World Health Organization that has been in use to ascertain cause of death. Details of verbal autopsy (VA) methods have been reported elsewhere [9,10]. Briefly, every death occurring in the HDSS area is recorded by community health research workers during bimonthly home visits and reported to the HDSS

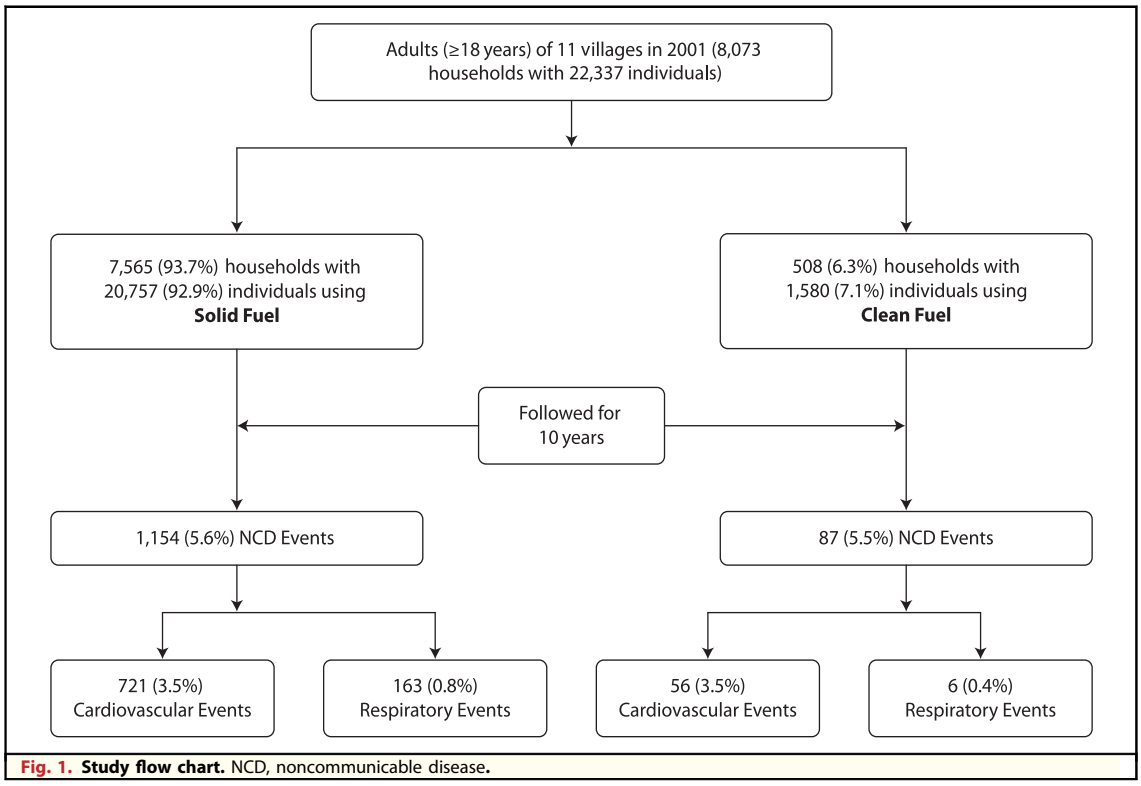

Fig. 1. Study flow chart. NCD, noncommunicable disease.

office. Then a senior field research assistant visits the household within 6 weeks of death and collects a detailed medical history leading to death, including care-seeking behavior and hospitalization. The report is then reviewed by an experienced paramedic/medical assistant who assigns direct and underlying cause of death using codes from the *International Classification of Diseases*, 10th revision (ICD-10). If the information is not sufficient or unclear to assign cause of death, the medical assistant reinterviewed the family member to collect further information to specify the cause. In rare occasions, if information remains insufficient to assign a cause, then the death is recorded as unspecified. Cardiovascular deaths included those that occurred due to disease of the circulatory system, which are included between codes I00 and I99, and respiratory deaths that had been assigned codes J00 to J99. Cardiopulmonary mortality included both cardiovascular and respiratory deaths.

Data analysis. The main exposure variable was fuel type, which was used as a surrogate for IAP exposure. Every household in which death occurred between 2001 and 2010 was assigned a fuel-supply status. The duration of exposure to solid fuel or gas supply before the event was calculated from January 1, 2001, until the date of death by subtraction. If the death occurred in the household within 6 months after receiving gas supply, the event was counted in the solid-fuel group. Total person-time of observation (exposure) in each fuel type was calculated for all participants from the start date to the end date (December 31, 2010) or the event, death or outward migration, or change of fuel type. Those who died due to causes other than cardiopulmonary diseases or that could not be ascertained or migrated out of the study villages were excluded. Incidence rates of cardiopulmonary mortality or subcategory for each fuel type were calculated using the number of events (deaths) divided by person-time of observation. Incidence rate ratio and 95% confidence intervals were calculated. Analyses were done using SPSS (version 17, SPSS Inc., Chicago, IL, USA) and STATA (version 10.1, StataCorp, College Station, TX, USA).

RESULTS

Of 39,035 individuals from 8,073 households in the 11 selected villages, 22,337 adults (46.5% men) 18 years or older, were available on January 1, 2001, of which 508 households with 1,580 adults residents had a liquid propane gas supply. Over the 10-year period, 1,721 individuals died, of which 1,617

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deaths took place in solid-fuel–using households and 104 deaths in the gas-supplied households. Deaths due to noncommunicable diseases (NCD), which included cardiovascular-, respiratory-, endocrine-, and cancer-related deaths, accounted for 1,241 or 72% of total deaths. Among NCD deaths, 777 were cardiovascular deaths (I00 to I99) and 169 died of diseases of respiratory system (J00 to J99). Cerebrovascular events (I60 to I69) ranked top among cardiovascular deaths, which accounted for 363 deaths, followed by ischemic heart disease, which caused 183 deaths. Among respiratory deaths, chronic obstructive pulmonary disease and allied conditions (J00 to J39) caused 57 deaths, and 85 deaths were attributable to respiratory tract infection (J40 to J47), and another 27 died of all other respiratory diseases (J60 to J99). Altogether, 946 deaths occurred due to cardiopulmonary causes, of which 884 occurred in solid-fuel–using and 62 occurred in gas-using households. In total, 5,625 people migrated out of the study villages. In total, 155,669 person-years of observation were available, of which 143,743 from those exposed to solid-fuel–using and 11,926 in the gas-using households. Figure 1 shows study participant flow.

Table 1 shows the characteristics of the deceased individuals. The mean age at death was 65 years and 56% of deaths occurred in men. However, age and sex distribution of deceased individuals did not differ significantly between the 2 groups neither did the occupation category. Of the total deaths, 5.5% occurred before 40 years of age and 71% occurred in the 60 years or older age group. The prevalence of smoking was 47% among those who died in the solid-fuel group compared with 38% among those from the gas-user group, but the difference did not reach statistical significance. However, gas-supplied households were relatively more educated and richer than solid-fuel–using households were.

Table 1. Characteristics of adult individuals who died of cardiopulmonary causes during the 10-year period (2001 to 2010) in relation to household fuel type in rural Matlab, Bangladesh

	Total (N = 946)	Solid (n = 884)	Gas (n = 62)	*p* Value
Age of the respondents, yrs	64.88 ± 13.45	64.96 ± 13.39	63.74 ± 14.26	
Age group, yrs				0.702
<40	52 (5.5)	48 (5.4)	4 (6.5)	
40 to 59	224 (23.7)	207 (23.4)	17 (27.4)	
≥60	670 (70.8)	629 (71.2)	41 (66.1)	
Sex				0.407
Men	532 (56.2)	494 (55.9)	38 (61.3)	
Women	414 (43.8)	390 (44.1)	24 (38.7)	
Level of education				0.000*
Illiterate	615 (65.0)	592 (67.0)	23 (37.1)	
Primary	206 (21.8)	184 (20.8)	22 (35.5)	
Secondary	96 (10.1)	86 (9.7)	10 (16.1)	
High	29 (3.1)	22 (2.5)	7 (11.3)	
Poverty index				0.000*
1	159 (18.3)	158 (19.5)	1 (1.7)	
2	132 (15.2)	131 (16.1)	1 (1.7)	
3	153 (17.6)	152 (18.7)	1 (1.7)	
4	163 (18.7)	158 (19.5)	5 (8.5)	
5	264 (30.3)	213 (26.2)	51 (86.4)	
Occupation				0.532
Manual	232 (24.9)	218 (25.0)	14 (23.3)	
Nonmanual	288 (30.9)	266 (30.5)	22 (36.7)	
Housewife	372 (39.9)	352 (40.3)	20 (33.3)	
Others	41 (4.4)	37 (4.2)	4 (6.7)	
Smoking status				0.287
Nonsmoker	325 (53.4)	305 (52.9)	20 (62.5)	
Smoker	284 (46.6)	272 (47.1)	12 (37.5)	

Values are mean ± SD or n (%).
* The chi-square statistic is significant at the 0.05 level.

Figure 2 shows the incidence rate ratio and the 95% confidence intervals (CI) (detailed data are presented in Table 2). All NCD mortality was 10% higher in the solid-fuel group than in the gas-using group, but the CI included unity. Cardiopulmonary deaths were 18% higher in the solid-fuel group, but again the CI was wide. Among cardiovascular diseases, cerebrovascular events were 35% higher among individuals from the solid-fuel group and deaths due to ischemic heart disease were 18% lower, but in both cases, the wide CI included unity. Deaths due to respiratory diseases were 2.26× higher in the solid-fuel group than in the gas-using group, and the lower bound of the 95% CI was >1. The pattern of mortality gradient was similar in both men and women, as observed in the total sample, but the CI

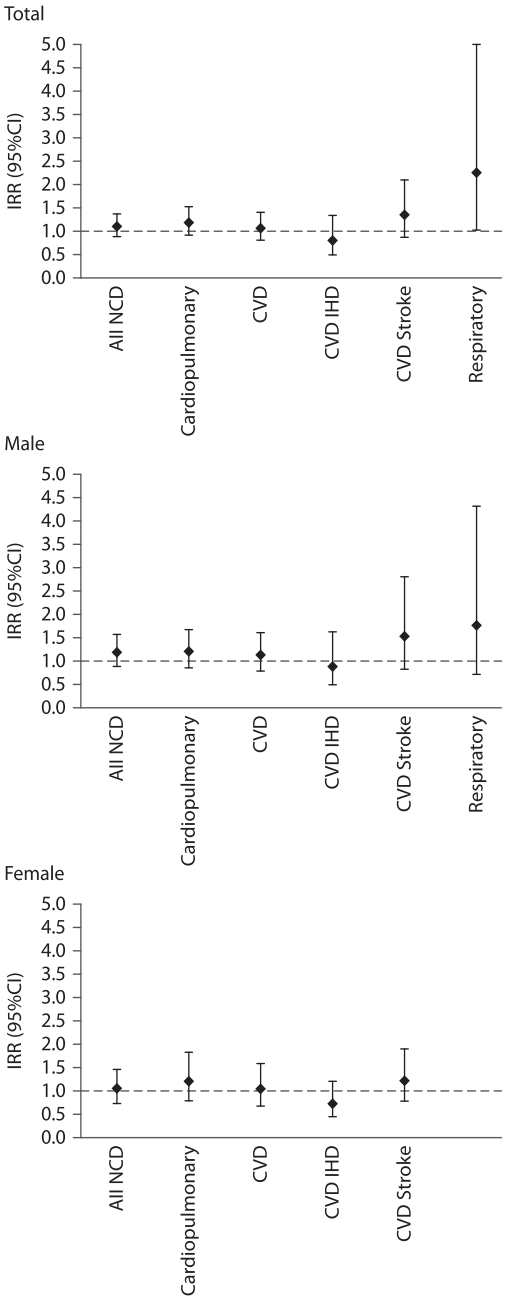

Fig. 2. Incidence rate ratio (IRR) and 95% confidence interval (CI) for cardiopulmonary mortality over a 10-year period (2001 to 2010) in relation to fuel type in rural Matlab, Bangladesh. Data are presented in Table 2.

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Table 2. Incidence rates and IRR (95% CI) in relations to household fuel type in rural Matlab, Bangladesh

	Fuel Type	Events, n	Total Observation Time (PY)	IR/1,000 PY	IRR	95 % CI	
						Lower	Upper
All NCD events	Solid	1,154	143,743	8.03	1.10	0.89	1.37
	Gas	87	11,926	7.30			
Cardiopulmonary events	Solid	884	142,415	6.21	1.18	0.91	1.53
	Gas	62	11,796	5.26			
CVD events	Solid	721	141,695	5.09	1.07	0.82	1.41
	Gas	56	11,782	4.75			
CVD-IHD events	Solid	166	138,835	1.20	0.82	0.50	1.34
	Gas	17	11,605	1.46			
Cerebrovascular events	Solid	342	139,844	2.45	1.35	0.87	2.10
	Gas	21	11,621	1.81			
Respiratory events	Solid	163	138,815	1.17	2.26	1.02	4.99
	Gas	6	11,545	0.52			
Men ≥18 yrs							
All NCD events	Solid	664	63,746	10.4	1.19	0.9	1.58
	Gas	52	5,933	8.8			
Cardiopulmonary events	Solid	494	62,910	7.9	1.21	0.87	1.68
	Gas	38	5,849	6.5			
CVD events	Solid	400	62,500	6.4	1.13	0.79	1.61
	Gas	33	5,837	5.7			
CVD-IHD events	Solid	115	61,029	1.9	0.90	0.50	1.63
	Gas	12	5,742	2.1			
Cerebrovascular events	Solid	181	61,482	2.9	1.54	0.84	2.81
	Gas	11	5,736	1.9			
Respiratory events	Solid	94	60,937	1.5	1.76	0.72	4.27
	Gas	5	5,700	0.9			
Women ≥18 yrs							
All NCD events	Solid	490	79,997	6.1	1.05	0.74	1.48
	Gas	35	5,993	5.8			
Cardiopulmonary events	Solid	390	79,505	4.9	1.22	0.81	1.83
	Gas	24	5,947	4.0			
CVD events	Solid	321	79,195	4.1	1.05	0.69	1.6
	Gas	23	5,945	3.9			
CVD-IHD events	Solid	51	77,806	0.7	0.77	0.31	1.92
	Gas	5	5,863	0.9			
Cerebrovascular events	Solid	161	78,362	2.1	1.21	0.64	2.29
	Gas	10	5,885	1.7			
Respiratory events	Solid	69	77,878	0.9	5.18	0.88	30.34
	Gas	1	5,845	0.2			

CI, confidence interval; CVD, cardiovascular disease; IHD, ischemic heart disease; IR, incidence rate; IRR, incidence rate ratio; NCD, noncommunicable disease; PY, person-years.

were wide. The overall findings suggest a higher mortality rate in the solid-fuel group.

DISCUSSION

We demonstrated that solid-fuel use is associated with excess risk of mortality due to overall NCDs, combined cardiopulmonary mortality, and cardiovascular and respiratory mortality in a rural area less affected by traffic or industrial pollution in Bangladesh. To our knowledge, this is the first study that has looked at the association between adult cardiopulmonary mortality due to IAP using fuel type (solid vs. gas) as a surrogate for IAP in low-income countries.

Household solid-fuel use is associated with significantly increased mortality from respiratory diseases and nonsignificantly increased risk of

cardiovascular mortality. Although our data are not sufficiently powered to make strong conclusions for all types of cardiopulmonary mortality, these findings have important public health significance considering the size of the population exposed. Further study is needed to investigate the contribution of IAP in the Bangladeshi population. Results suggest efforts to reduce exposure to pollution due to solid-fuel use are likely to improve survival.

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