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Household Air Pollution Is a Major Avoidable Risk Factor for Cardiorespiratory Disease

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Household air pollution (HAP) from biomass fuels, coal, and kerosene burned in open fires, primitive stoves, and lamps causes at least 2 million deaths per year. Many of these deaths occur in children <5 years of age with pneumonia and in women with COPD, lung cancer, and cardiovascular disease. HAP is inextricably linked to poverty, with activities to obtain fuel consuming a large proportion of the time and financial resources of poor households. Thus, fewer resources used in this way means less is available for basic needs like food, education, and health care. The burden of work and the exposure to smoke, particularly during cooking, are predominantly borne by women and children. Although historically HAP has not received sufficient attention from the scientific, medical, public health, development, and policy-making communities, the tide has clearly changed with the broad-based support and launch of the Global Alliance for Clean Cookstoves in 2010. There is now considerable reason for optimism that this substantial cause of cardiorespiratory morbidity and mortality will be addressed comprehensively and definitively. Drawing on our experience from four continents, we provide background information on the problem of HAP, health impacts of HAP, opportunities for research, and the current best solutions. ***CHEST 2012; 142(5):1308–1315***

Abbreviations: HAP = household air pollution; RESPIRE = Randomized Exposure Study of Pollution Indoors and Respiratory Effects; WHO = World Health Organization

Almost one-half of the people on the planet burn biomass fuels (wood, charcoal, dung, or crop residues), coal, and/or kerosene (paraffin) as energy sources for cooking, heating, and lighting within their households.[1-3] The smoke from the incomplete combustion of these fuels is often so thick and oppressive that visitors unaccustomed to this level of household air pollution (HAP) can only be inside these homes for a few minutes before tears and coughing drive them outside for relief (Fig 1). People living in these conditions are extremely poor, often living on < $1-2 per day. Life at the bottom of the energy ladder places family members, mostly women and children, at great risk for lifelong poor health.

As tobacco is biomass, it will not surprise chest physicians that women and children exposed to HAP from biomass or coal exhibit some of the same health risks as smokers. For example, both COPD and lung cancer account for 1.1 million deaths every year in nonsmoking women, and this occurs almost exclusively in lower- and middle-income countries. The World Health Organization (WHO) estimates that based on data from 2004, almost 2 million deaths occur every year from HAP. Almost one-half of these

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Figure 1. Typical scenes of women cooking indoors in smoky environments from around the world. A, An Indian woman trying to ignite dried dung in a brick stove releasing a lot of smoke. B, An Ethiopian woman preparing to cook injera over a three-stone fire in a wooden outbuilding. C, A Malawian woman cooking over a three-stone fire in the type of building that would also be used as living and sleeping quarters. D, A Peruvian mother holding a young child while cooking in a smoky kitchen blackened by soot. Particulate matter and carbon monoxide exposures in these settings significantly exceed what are considered safe levels for indoor and occupational environments in developed countries. The individuals shown in the figures gave verbal permission to the authors for publication of the pictures.

deaths are from pneumonia in children under the age of 5 years.[1,2] This estimate of nearly 2 million deaths annually is probably low, and the updated global burden of disease estimate due to be published later this year is expected to be much higher, due primarily to inclusion of the additional risk of morbidity and mortality from cardiovascular diseases.

Despite the current burden of disease, there is reason for optimism that this environmental insult that affects the world's poor and causes major cardiorespiratory morbidity and mortality will now be addressed in a comprehensive and sustainable way. The Global Alliance for Clean Cookstoves is a public-private partnership within the United Nations Foundation that was launched in September 2010 to achieve the goal of 100 million homes adopting clean cooking technology by 2020 (http://cleancookstoves.org). The US government, along with multiple departments and agencies, is a founding partner of the Global Alliance for Clean Cookstoves. Hundreds of partner countries, companies, foundations, and others share the short- and long-term vision to prevent HAP-associated death and disease. Engaged physicians and scientists will be an integral part of either the success or failure of this ambitious goal, and this article will provide a review of the subject as well as some of the opportunities ahead to improve human health on a global scale.

HAP in Context

The Indian Subcontinent

More than 75% of households in India use dried cattle dung (Fig 2), crop residue, and firewood for domestic fuels that are most commonly burned in open three-stone fires.[4] In exposure studies, the use of dung was associated with high concentrations of indoor pollutants, followed by other fuel types.[5] Similarly, pollutant concentrations in kerosene-using houses were twice those seen in gas-using homes. Mixed-fuel use in India is common in most kitchens. There is poor efficiency of energy conversion to heat in most of the solid-fuel stoves, with 6% to 20% of the fuel-carbon converted to toxic substances. In India, >0.4 million deaths and about 3.5% of the national burden of disease are attributed to the combustion of biomass fuels.[6] Of the total annual deaths attributable to HAP, some 250,000 to 400,000 occur from acute lower respiratory tract infection in children of <5 years of age and 20,000 to 155,000 occur due to COPD in women.[6,7]

Africa

The use of biomass fuel in traditional three-stone fires is ubiquitous in much of rural sub-Saharan Africa. The drudgery of collecting firewood in the context of subsistence farming is common, with nomadic pastoralists burning dung in more arid regions. Assessment of the health impacts of HAP is very difficult owing to the confounding factors of malnutrition, stunting, and repeated infections. What is known is the following: (1) The prevalence of chronic lung disease is high, (2) children under the age of 5 years are at serious risk of acute pneumonia,[8] and (3) domestic exposures to cooking and lighting smoke are high and

Figure 2. Heaps of cattle dung being dried in the sun and ready for burning in household fires. Dung is a popular renewable fuel in settings where animals are kept and in more arid areas where other fuel types are scarce. Combustion of dung generates smoke with particular characteristics, including high levels of endotoxin.

well beyond WHO-recommended limits.[9,10] Data also show that domestic smoke exposure results in carbon loading of alveolar macrophages,[11] and alveolar macrophage loading (Fig 3) is associated both with spirometric abnormality and with functional defects associated with impaired resistance to oxidative stress (Stephen B. Gordon, MD, unpublished data, 2011). Fuel collection has additional health risks in long-standing refugee camps, where the burning of locally available biomass has created several miles-long zones of deforestation. This places women at high risk for sex-based violence as they walk many miles away from the safety of their homes and families to collect fuel.

Latin America

In rural Latin America, biomass fuels are commonly used for cooking, and even in many urban areas there is considerable use of wood. However, large variations are seen across the continent and within countries. For example, <5% of households in Argentina use biomass fuels for cooking compared with around 62% of households in Guatemala.[6] In areas >4,000 m above sea level, as in the Andes, dung is commonly used. Exposure to smoke depends on many interacting factors, including the type of stove (commonly open fire), fuel type and moisture content, weather conditions, ventilation, and behavior around the fire, including in which room the fire is located.[12] Exposures can be especially high for women and children living in cold areas like the Peruvian highlands, where stoves are used indoors and often in the only room of the house (Fig 1D). In Peru in 2002, 1,230 children aged <5 years died of pneumonia and 47,900 disability-adjusted life-years were lost, attributable to solid fuel use,[6] underscoring the need for proven sustainable interventions to combat HAP.

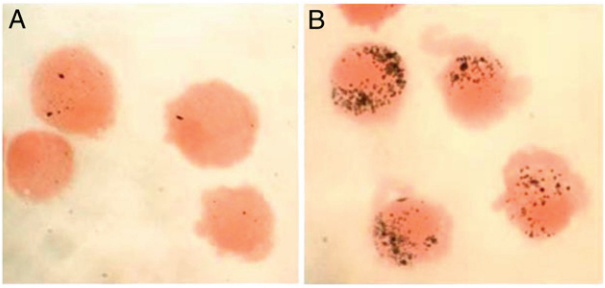

Figure 3. BAL cytospin samples from two Malawian, nonsmoking volunteers who underwent bronchoscopy at the Queen Elizabeth Hospital in Blantyre, viewed under light microscopy. The alveolar macrophages shown contain very different amounts of cytoplasmic particulate matter that likely reflect differences in individual household air pollution and other types of air pollution exposure. A, Minimal inclusions. B, Striking amount of inclusions. The extent of alveolar macrophage particulate loading may be a useful biomarker of biomass smoke exposure. The potential prognostic significance of particular matter burden is currently uncertain.

The United States and Other Industrialized Countries

Wood and coal are still used for cooking and/or heating in many rural areas of the United States and Canada, especially in certain Native American tribal homelands.[13,14] Of note, use of high-efficiency particulate air filters as an intervention to reduce HAP results in improved endothelial function and a decrease in inflammatory biomarkers, suggesting a possible decrease in cardiovascular risk.[15] A study from Spain demonstrated that cooking with wood was associated with an increased risk of COPD.[16] HAP remains a major public health problem for the poor in many countries (eg, China) that have undergone substantial industrialization, but where access to clean energy is far from universal. This highlights that HAP is strongly linked to issues of poverty and disparity, and while industrialized nations have moved the majority of their population up the energy ladder, people in poor and rural areas are still strongly impacted by HAP.

Health Impacts of HAP

There is an increasing body of epidemiologic evidence to show that the spectrum of adverse health effects from HAP is the same as that for tobacco smoking. The magnitude of the exposure effect is somewhere between passive and active tobacco smoke exposure.[17,18] Here we highlight some of the evidence to associate household smoke exposure with pneumonia, COPD, asthma, cancer, TB, and cardiovascular disease.

Pneumonia

Pneumonia is the leading cause of death in children aged <5 years in the world.[19] A systematic review and meta-analysis of the literature calculated an overall pooled OR of 1.78 (95% CI, 1.45-2.18) for the association between HAP from unprocessed solid-fuel use (including coal) and increased pneumonia risk in children <5 years of age.[20] The latest estimate suggests an OR of 3.52 (95% CI, 1.94-6.43).[21] In contrast, there is virtually no information about the impact of HAP on neonatal pneumonia or maternal sepsis, and yet, these account for significant mortality in lower- to middle-income countries.[22] It is likely that this smoke exposure is also an important risk factor for pneumonia in adults.[23]

Preventing Pneumonia by Reducing Exposure to Biomass Smoke: The RESPIRE (Randomized

Exposure Study of Pollution Indoors and Respiratory Effects) trial in highland Guatemala randomized 534 households with a pregnant woman or infant to receive a chimney stove ("plancha") or retain the traditional three-stone open fire. The researchers then assessed the impact on pneumonia in children until age 18 months.[24] Although the intervention was not associated with a significant reduction in all physician-diagnosed pneumonia, there was a significant reduction in severe pneumonia as defined by hypoxemia (relative risk, 0.67; 95% CI, 0.45-0.98). This significant effect on severe pneumonia was achieved with a 50% reduction in personal smoke and carbon monoxide exposures. An exposure-response relationship was seen between biomass smoke exposure and pneumonia risk with the risk rising steeply at low levels and flattening off at higher levels of exposure (Fig 4). This suggests that a 50% to 90% reduction in exposures may be required to have a major reduction in child pneumonia globally. The plancha is not a clean-burning stove; its chimney merely vents the smoke outside, where it can freely re-enter the home. The RESPIRE results strongly suggest that cleaner biomass-fuel-burning stoves, implemented in a way that substantially reduces smoke exposures (including exposures from neighboring homes), could cause measurable and meaningful reductions in childhood pneumonia.

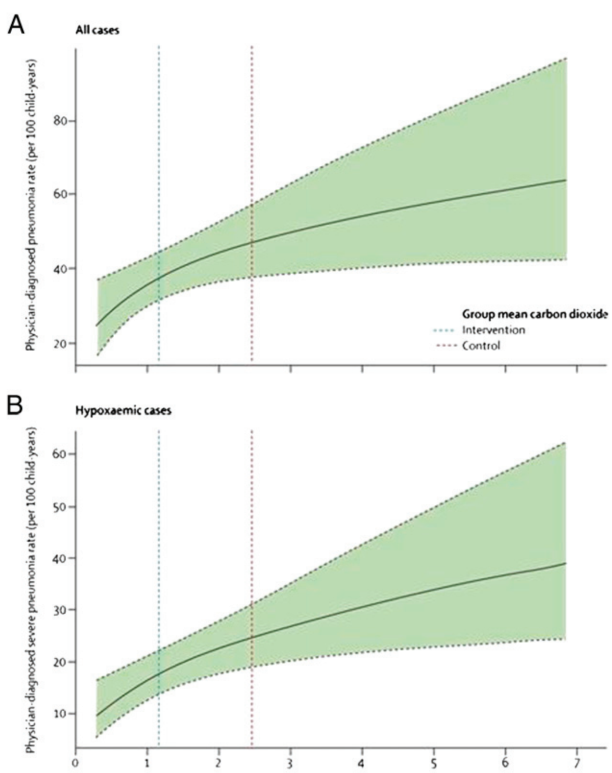

Figure 4. Exposure response for personal carbon monoxide concentrations in study children for pneumonia from the RESPIRE (Randomized Exposure Study of Pollution Indoors and Respiratory Effects) study. In the RESPIRE trial, personal carbon monoxide exposures were monitored in the study children. A, Carbon monoxide exposures in relation to the risk of physician-diagnosed pneumonia. B, Carbon monoxide exposures in relation to physician-diagnosed severe (hypoxemic) pneumonia.[24] It is likely that substantial reductions in personal exposures to the partial combustion products in biomass smoke will be needed for the full health benefits of clean cookstove interventions to be seen. Reprinted from Smith et al[24] with permission from Elsevier.

COPD and Asthma

There is good evidence that exposure to smoke from solid-fuel combustion is associated with an increased risk of COPD,[25-27] respiratory symptoms,[28] and chronic bronchitis.[29,30] In places as different as Latin America and China, a substantial proportion of COPD occurs in never-smoking women.[31-33] In China, for example, only 24% of women with COPD were smokers.[31] Smoking is much less common among women in rural than urban settings. The prevalence of COPD among rural women, however, is three times higher than urban women and this is associated with exposure to HAP.[33] In such settings worldwide, the proportion of COPD attributable to exposure to household smoke is likely to be high.[34]

Since smoking cessation can reduce the rate of decline in FEV_1 among tobacco smokers, the same effect could be expected from reductions in HAP. Romieu et al[35] conducted a randomized controlled trial of a Patsari chimney-stove intervention compared with the traditional open fire on respiratory symptoms and lung function in 552 women in the Mexico. Adherence to the intervention was poor (50%), but the Patsari stove reduced respiratory symptoms (eg, rate ratio for wheeze, 0.29; 95% CI, 0.11-0.77) and lung function decline (31 mL vs 62 mL over 1 year; $P = .01$) in those who used the stove, providing some evidence that a stove intervention that reduces smoke exposure may reduce the risk of COPD development and progression.[35] In the RESPIRE trial, mothers of study children in the intervention group had reduced respiratory symptoms (OR, 0.7; 95% CI, 0.50-0.97) during the 12-18 months of follow-up, but there was no effect on lung function during this short follow-up of relatively young women (mean age, 28 years).[24]

Studies that have explored the association between biomass smoke exposure and asthma have yielded somewhat conflicting results. Where positive (and negative) associations have been observed, the effect sizes are generally small. The systematic review and meta-analysis by Po et al[21] provides a useful summary. They combined data from four studies to calculate a pooled OR of 0.50 (95% CI, 0.12-1.98) for biomass fuel exposure and asthma in children.[21] Although inconclusive, the effect estimate is in the direction of protection. For asthma in women, the pooled OR based on data from five studies was 1.34 (95% CI, 0.93-1.93).[21] Heterogeneity in study design, populations, outcome measurements, low statistical power, and the few publications in this area are notable limitations. There is a need for well-designed and adequately powered studies to explore the association between HAP and asthma.

Lung and Upper Airway Cancers

The International Agency for Research on Cancer has reviewed the evidence that smoke from the household combustion of coal and biomass is carcinogenic and rated these as "carcinogenic to humans (Group 1)" and "probably carcinogenic to humans (Group 2A)," respectively.[36] There is particularly strong evidence from studies conducted in China that smoke from household burning of coal is associated with lung and upper airway cancers.[37,38] There is also evidence that smoke from biomass burning is associated with lung cancer,[39,40] but this is a under-researched area and one that deserves considerably greater attention. A causal association is highly plausible.

TB

There is a long-established association between poorer standards of living and higher risks of TB. Since HAP is a feature of poverty, an association between HAP and TB is expected. After adjustment for potential confounders, an association between biomass smoke and TB has been seen in studies from India and Nepal.[41,42] The Nepal study found a particularly high risk of TB associated with the use of kerosene lamps for lighting, with an OR of 9.43 (95% CI, 1.45-61.32).[42] Many of the studies in this area have, however, been limited by bias and residual confounding (particularly other poverty-related factors), and exposure assessments have often been questionnaire based. More robust data are needed to clarify whether HAP is associated with an increased risk of TB acquisition and activation.[43]

Cardiovascular Risks

Given that smoke exposures from HAP are between exposure levels associated with active and passive cigarette smoking, it is highly plausible that HAP would be associated with higher risks of ischemic heart disease and stroke.[17,18] The direct evidence is limited, but there are supportive data from a small number of studies, including a study from rural India in which hypertension and blood markers were associated with biomass fuel use,[44] and the RESPIRE study from Guatemala, in which the chimney-stove intervention was seen to reduce both BP and ST segment depression.[45,46] Further, there is a recent cross-sectional analysis of >14,000 adult Chinese that demonstrates that HAP is associated with increased risk for hypertension, coronary heart disease, stroke, and diabetes, after adjusting for potential confounders.[47] There remain major gaps in our knowledge about the causal association between HAP and cardiovascular disease development, but it is clear that there is increasing evidence for a high global burden of cardiovascular disease attributable to HAP.

Other Health Risks

Although we have focused our discussion on the cardiorespiratory health effects of HAP, there are serious concerns about other adverse health effects. In particular, these include poor pregnancy outcomes and perinatal risks (eg, birth defects, low birth weight, sepsis),[48] and impaired child physical and cognitive development.[49,50] Also, there are concerns that household burning of fuels for cooking, heating, and lighting results in ocular disease (eg, cataracts),[51] direct risks of open fires (eg, burns, scalds, house fires), and indirect risks relating to fuel collection (eg, sex-based violence, children missing school).[52] Finally, there are increasingly compelling data to suggest that early life events such as low birth weight, undernutrition, and/or environmental exposures may pose life-long risks for noncommunicable diseases, such as airway diseases and cardiovascular diseases.[53-55]

Opportunities for Research

There are important gaps in our understanding of HAP disease associations that need to be addressed to identify clearly the health risks and the specific strategies that can be implemented to offset premature death and disabilities for millions. In particular, a better understanding of the risk of pneumonia in adults, TB, lung cancer, and cardiovascular diseases in people exposed to HAP is needed. At the same time, faced with an avoidable risk factor that is responsible for potentially as many as 4 million deaths a year worldwide, we cannot wait for a complete evidence base before taking action. Instead, we should use the best available evidence to craft interventions and put into place sufficient monitoring so that we can learn from and improve future interventions. The central question for these interventions should be: How clean does indoor air need to be to achieve the maximum health benefit? As a starting point, the WHO has proposed WHO Indoor Air Quality guidelines using available evidence to show the levels of indoor air concentrations of pollutants that appear safe and consistent with promoting good health (www.who.int/indoorair). Assuming that clean-air interventions can be applied in situations of extreme poverty, can these interventions be made affordable? To what extent will "less dirty" interventions be effective and cost effective at improving health? Answers to these questions will come from a combination of research approaches spanning basic science, and observational and intervention studies. We need a much better understanding of smoke exposure-response relationships, biomarkers of exposure and disease risk, and effective emission- and exposure-reducing interventions (including behavioral changes and advanced fuel, stove, and ventilation technologies). There is a clear need for high-quality clinical trial evidence about the principles that influence households to adopt exclusive use of clean energy solutions, and the resultant health, economic, and environmental impacts seen when this occurs. Finally, this information must be translated in a way that helps impoverished communities and informs better public policy.

Toward Solutions

Alongside the need for research, there is a clear need for decisive action. The challenge this represents is not unlike the major challenges of the past that have required science, clinical medicine, and public health measures to decrease the global burden of disease. TB in the first one-half of the 20th century and tobacco-related illnesses in the second one-half serve to remind us of the challenges and the decades of commitment required to improve human health. The scale of the HAP problem is daunting for many reasons, including the estimated 500-800 million households that would need to fundamentally change how they use energy within their households on a sustainable basis.

Ultimately, HAP is a problem of poverty and global inequality of access to clean energy. There is cause for optimism, however, as there are other spheres in which technology has driven major positive change. For example, in the world of telecommunications, many of the poorest people in the world jumped straight from having nothing to using cell phones. Can we draw inspiration from this transformation and get people at the bottom of the energy ladder to the top quickly? Efficient-burning, fan-assisted biomass cookstoves (eg, BioLite [Biolite] and Philips Design stoves [Royal Philips Electronics]) with substantially lower smoke emissions than traditional fires or stoves are already available. These blower stoves have many advantages: They are cheaper, safer, faster, and more portable than gas, controllable like gas, and consume renewable fuels.[56] The challenge of scale can be reached by motivated governments, industries, and nongovernmental organizations. As an example, Indonesia and its government-owned oil and gas company, Pertamina, helped almost 50 million households convert to clean liquefied petroleum gas gas stoves from 2007 to 2010. In Peru, the government has led a successful country-wide intervention campaign introducing half a million improved stoves for "a Peru without smoke."[57] The new generation of advanced stove and fuel technologies offers real opportunities to effect a step change in access to clean energy for communities who currently cook over open fires. Good evidence already exists that many of these new technologies are highly acceptable and desirable. The higher costs of obtaining these advanced stoves, while a disadvantage, can be reduced through economies of large-scale production, subsidies, capitalizing on the carbon-credit market, and offsetting some of the initial investment against reduced fuel consumption.

Large-scale implementation of cooking solutions is possible with available technology and will bring direct health benefits.[22] In addition, there are direct and indirect benefits to local communities, such as stimulation of local economies, fuel security, carbon finance income, time released from fuel-collecting tasks used for other positive activities, reduction in risk of exploitation, and the empowerment of women and children.[58] There are also major environmental benefits, including less deforestation, particularly where biomass fuel production is combined with tree-planting programs; reduced outdoor air pollution; and reductions in short-lived climate forcers, such as black carbon, that have major global-warming potential.[59] Integrated interventions that simultaneously tackle the lack of access to clean energy as well as other poverty-related issues, such as access to clean water, sanitation, nutritious food, health care (including vaccinations), and adequate shelter are likely to have the greatest overall benefits. The biomedical and stove-research communities will need to move quickly to ensure the solutions adopted provide household air quality that is actually clean enough to prevent the millions of deaths that occur each year from biomass smoke exposure. If we achieve this, then we really will be "cooking with gas."

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