

REVIEW

Air pollution and children's respiratory health – gaps in the global evidence

J. Grigg

Centre for Paediatrics, Blizard Institute, Barts and the London School of Medicine and Dentistry, Queen Mary University London, London, UK

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Summary

There is now convincing evidence that air pollution, especially the particulate matter (PM) fraction, adversely affects children's health. In general, the health effects of traffic-derived PM are well described in children living in high-income countries. Conversely, studies into the health effects of PM from biomass and solid fuels are limited to children in lower-income countries. As PM from different combustion sources have components in common (e.g. elemental black carbon) – are we able to extrapolate from the research performed in different countries under different exposure conditions? Using lung function growth and vulnerability to infection as examples of health effects of global significance to children, this review addresses the question whether high-income-country research into air pollution can inform effects of pollution in low-income countries and *vice versa*.

Correspondence:

Professor Jonathan Grigg, Centre for
Paediatrics, Blizard Institute, Barts and
the London School of Medicine and
Dentistry, Queen Mary University
London, 4 Newark Street, London E1
2AT, UK.
E-mail: j.grigg@qmul.ac.uk

Lung function growth

There is now convincing evidence that air pollution, especially the particulate matter (PM) fraction, adversely affects children's health [1]. Not only are children with low lung function more susceptible to clinical symptoms, but also poor lung growth during childhood increases the risk of respiratory problems during adulthood [2]. To date, the most convincing evidence that air pollution impairs children's lung growth is provided by a longitudinal study of children in 12 communities in California, which found an association between reduced lung function growth and the background concentration of $PM_{10} < 10 \mu m$ in aerodynamic diameter (PM_{10}) between communities [3]. In a cross-sectional analysis of the final dataset of the California study, a higher proportion of adolescents with a forced expiratory volume in 1 s (FEV_1), $< 80\%$ predicted, was found in communities with the highest background concentrations of 'black' carbon PM [3]. It is therefore, very likely, as suggested by a recent systematic review [4], that 'long-term exposure to traffic emissions is associated with changes in lung function in adolescents and young adults, and lung function measures are lower in people who live in more polluted areas'. To date, the component of fossil-fuel-derived PM responsible for attenuating lung function

growth remains unclear. Indeed, a role for other pollutants generated at the same time, such as nitrogen dioxide, has not yet been excluded. However, evidence that the elemental black carbon fraction of PM is closely associated with the pathogenic component is provided by a study by Kulkarni et al. [5] that used the amount of black carbon in lower airway macrophages to assess the inhaled dose of PM. In healthy children living in Leicester, UK, this study found that an increase of $1.0 \mu m^2$ in the mean area of black carbon in airway macrophages was associated with a -17% change in FEV_1 [5, 6]. What relevance do these data have to (i) children living in low-income cities where PM exposure is not only from traffic, but from the burning of charcoal, wood and coal, and (ii) children living in rural homes using biomass for cooking and heating? Certainly an important component of PM from fossil-fuels, biomass-fuels, solid-fuels and cigarette smoke, is inhalable aggregates of elemental carbon nanoparticles [7–9] with an intrinsic capacity to deliver oxidative stress to lower airway cells [10]. But there are also important quantitative differences between PM from different sources. For example, we recently found that PM from dung smoke has increased oxidative capacity compared with PM from diesel [11]. To date, there are no longitudinal studies of lung function growth done in children exposed to either

biomass smoke (e.g. in rural areas of Nepal/Africa), or to mixtures of fossil- and solid-fuel emissions (e.g. in Chinese cities). Indirect evidence that attenuation of lung function growth occurs in low-income environments is however provided by three cross-sectional studies of lung function. First, He et al. [12] reported lower levels of lung function in healthy school age children living in the central area of Wuhan, China [-6.7% forced vital capacity (FVC) and -3.8% FEV₁], compared with children living on the periphery of the city exposed to significantly lower PM levels. Second, Padhi and Padhy [13], measured lung function in 1505 Indian children living in households that either used biomass or liquefied petroleum gas (LPG), and found that children in biomass fuel households had significantly lower lung function compared with LPG households (FVC = 2.1 vs. 3.8 L; FEV₁ = 2.3 vs. 2.9 L). Third, in a study of healthy Mongolian children, Dashdendev et al. [14] found that 'normal' FEV₁ was 40% higher, in children living in rural areas compared with those living in urban areas. None of these studies address which PM source is most damaging to children's lung function growth. Even if, as suggested by the study in Mongolia [14], biomass PM is less damaging to lung function growth, this may well be negated by the much higher indoor concentrations of PM found in rural homes. Although many uncertainties in the evidence base remain, it is probable that the normal curve of 'healthy' lung function in children in lower-income countries is shifted by chronic exposure to PM. Large, well-designed, longitudinal studies of air pollution and lung function growth are therefore urgently needed in low-income countries – ideally recruiting children in both urban and rural areas, and with accurate source apportionment.

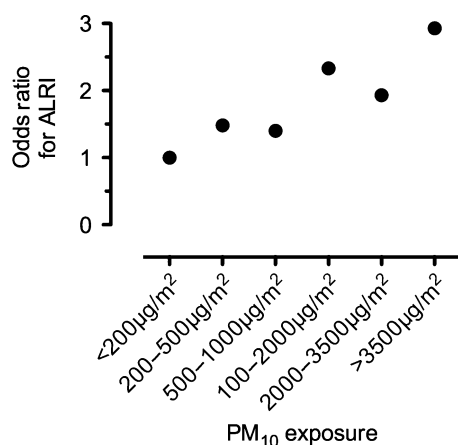


Fig. 1. Dose-response relationship between exposure to particulate matter <10 diameter (PM₁₀) from indoor biomass combustion and the risk (odds ratio) of acute lower respiratory tract infection (ALRI) in a 2-year longitudinal study of 93 Kenyan children aged <5 years. Adapted from tabular data presented in the study by Eazzti and Kammen [16]. The lower part of the dose-response curve exceeds PM exposures usually measured in urban areas in high-income countries.

Vulnerability to infection

Pneumonia is a leading cause of death among young children [15]. The association between air pollution and severe lower respiratory tract infection has mainly been defined in children living in low-income countries. For example, Ezzati and Kammen [16], studied 93 Kenyan infants and young children over 2 years, and reported a significant association between the concentration of indoor PM₁₀ from biomass smoke and risk of acute lower respiratory tract infection (Fig. 1). A recent meta-analysis of 24 indoor air pollution studies by Dherani et al. [17], found a 1.8-fold increase in risk of pneumonia in young

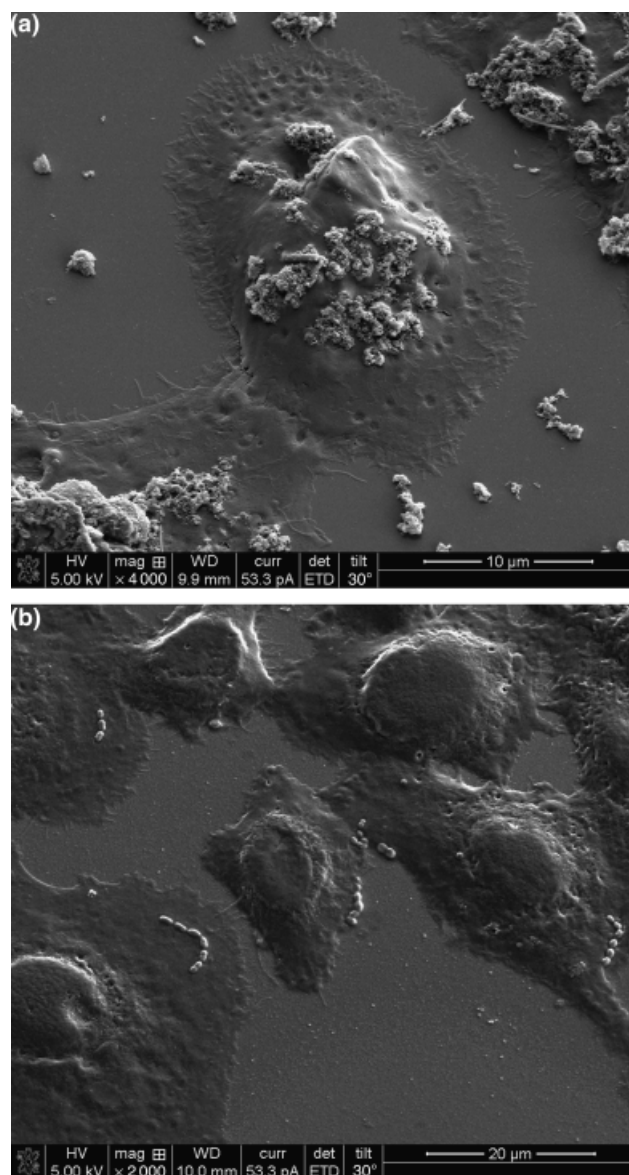


Fig. 2. Scanning electron microscopy images of A549 cells after culture with either; (a) PM₁₀ (UK). The white irregular surface material is particulate matter, or (b) *Streptococcus pneumoniae*. Pneumococci in chains and are adherent to the cell surface.

children with indoor solid fuel use. Furthermore, a meta-analysis by Po et al. [18] reported that exposure to wood, dung, crop residue or charcoal was associated with acute respiratory infections in children [odds ratio (OR) 3.53, 95% CI 1.94–6.43]. These OR are comparable to the risk of hospital admission with pneumonia (OR 1.55, 95% CI 1.25–1.92) [19], or acute respiratory infection (OR 1.55, 95% CI 1.42–1.69) [20], in young children exposed to environmental tobacco smoke. The only large high-income country study, performed in Australasia, found a 2.4% (95% CI, 0.1–4.7%) increase in hospital admissions for doctor-diagnosed 'pneumonia or bronchitis' in young children for each inter-quartile increase in urban PM_{2.5} [21]. The paucity of data on air pollution and infection in high-income countries is, in part, due to the low prevalence of severe pneumonia, and it has been left to laboratory studies to establish biological plausibility. First, chronic exposure to cigarette smoke, followed by infection with *Streptococcus pneumoniae* in mice results in increased numbers of bacteria in lung tissue and more severe clinical signs of sepsis [22]. Second, instillation of fossil-fuel-derived PM into the lower airways of mice impairs the clearance of *S. pneumoniae* [23]. Third, we recently reported that exposure to PM from both Accra, Ghana (where PM are a mix of fossil and biomass fuels), and Leicester, enhances the capacity of *S. pneumoniae* to adhere to human lower airway cells *in vitro* [24] (Fig. 2a, b). We did, however, find that Accra PM was less effective in stimulating adhesion [24]. Overall, it is plausible that fossil-fuel-derived PM increases vulnerability to bacterial

pneumonia, but it remains unclear if there is a significant effect at low concentrations of PM common to high-income urban environments.

In conclusion, advances have been made in understanding the global health burden of air pollution in children. For some health effects, there may now be sufficient breadth of data to derive a global perspective. For example, a recent meta-analysis of data from 51 paediatric populations – including children in Thailand and Mexico – found a significant association between short-term urban background level of PM₁₀ from traffic and asthma symptoms (OR 1.028, 95% CI; 1.006–1.051) [25]. But major discontinuities in the global evidence base remain. Researchers in high- and low-income countries can certainly learn from the work of each other, but to date, there is insufficient laboratory evidence to justify extrapolation of dose/response associations across the different combustion sources. Further epidemiological research in both high- and lower-income countries is therefore still needed in order to more accurately establish the global burden of air pollution, and to convince policy makers of the cost-effectiveness of exposure-reduction strategies.

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