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REVIEW

Smoke and malaria: are interventions to reduce exposure to indoor air pollution likely to increase exposure to mosquitoes?

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Summary Indoor air pollution from the domestic use of biomass fuels by poor households in developing countries is known to be harmful to health, and efforts are being made to address this problem by changes in fuel type, stove technology, house design and fuel-use practices. However, anecdotal evidence suggests that smoke may play an important role by providing protection from biting insects and that efforts to reduce smoke may increase exposure, particularly to mosquitoes and malaria. This paper reviews the literature relating to the repellent effect of smoke on mosquitoes and finds that there is currently no evidence that smoke from domestic fuel use provides effective protection from mosquitoes and malaria. Given the limited number and quality of studies, this finding cannot be interpreted as conclusive. The literature relating to house ventilation and mosquito entry was also reviewed, and an association between eaves spaces and increased indoor mosquito density was noted. Additionally, literature on the effect of soot on the efficacy of insecticide-treated bed nets was considered, but no direct impact was shown. Efforts to reduce indoor air pollution remain desirable even in areas of malaria transmission.

1. Introduction

Biomass fuels such as wood, dung and crop residues or coal are the primary household energy source for an estimated 3.2 billion people (WHO, 2006). It is estimated that exposure to indoor air pollution from these fuels results in around 1.5 million deaths annually from chronic respiratory diseases and acute respiratory infections (Smith et al., 2004; WHO, 2002, 2006). Efforts have been made to address this global health problem. Usually these have focused on reducing smoke through improved stoves that burn fuels more cleanly and more efficiently, on cleaner fuels or on removing smoke through improved house ventilation, chimneys or flues. However, smoke is also anecdotally claimed to repel biting insects (Davis and Bowen, 1994; Moore and Lenglet,

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2004), and house ventilation can provide entry points for insect vectors. It is therefore possible that interventions designed to reduce levels of indoor smoke might exacerbate the threat from malaria (transmitted through biting by infected mosquitoes of the *Anopheles* genus). On the other hand, it is possible that the effectiveness of insecticide-treated bed nets (ITNs), a cornerstone of modern malaria control, may be impaired by the soot in smoky environments and that removing smoke could be beneficial for preventing malaria.

More than 90% of child malaria deaths occur in poor, rural areas of sub-Saharan Africa (Bryce et al., 2005). The vast majority of African communities depend on biomass fuels for cooking. An estimated 360 000 African children die annually as a result of indoor air pollution (WHO, 2006) and this is more than one-third of the global child deaths from this risk factor. Understanding the possible interaction between interventions to prevent malaria and those to reduce indoor air pollution has important policy implications in this context.

This paper reviews and brings together published studies to consider the following three issues. What is the evidence that smoke from domestic biomass fuels repels mosquitoes and prevents malaria? What is the evidence that increased household ventilation increases exposure to mosquitoes? And what is the evidence that soot from domestic biomass fuels impairs the effectiveness of ITNs?

2. Methods

A search of the PubMed database was carried out. The terms biomass, burn, combust*, cook*, dung, fire*, indoor air pollution, smoke, stove*, fuel, coal and charcoal were combined with the terms *aedes*, *anophel**, *culex**, *culicidae*, malaria*, mosquito*, *ochlerotatus*, vector*, vector-borne, bite, biting, blood meal, feeding behaviour, feeding pattern*, resting behaviour and resting pattern*. This search was carried out on 12 June 2006. A second search of the PubMed database was performed to identify literature relating to house construction, ventilation and malaria transmission. The terms house construction, eaves and window* were used in combination with the terms *aedes*, *anophel**, *culex**, *culicidae*, malaria*, mosquito*, *ochlerotatus*, vector*, vector-borne, bite, biting, blood meal, feeding behaviour, feeding pattern*, resting behaviour and resting pattern*. The search was carried out on 20 June 2006. All articles were selected by title in the first instance and abstracts were read. Relevant articles selected on the basis of abstracts were read in full.

Further material came from a search of the Global Health Archive, which covers literature from 1910 to 1972. It is derived from a number of old bibliographic journals and covers a large part of the old vector control literature that is not included in modern databases and cannot otherwise be searched electronically. Additional material also came from the personal collection of one of the authors (M.C.) and was identified through discussions with entomologist colleagues at the London School of Hygiene and Tropical Medicine and other experts in the field.

Literature relating to the use of plant-based essential oils is not considered here but has been reviewed by Curtis et al. (1990).

3. Results

3.1. Does smoke repel mosquitoes and prevent malaria?

The search found no randomised controlled trials or systematic reviews of the effectiveness of smoke from wood or plant material either to repel mosquitoes or to prevent malaria.

3.1.1. Smoke from domestic fuels

One small experimental study was found on the effectiveness of smoke from firewood as a mosquito repellent in Sierra Leone (Bockarie et al., 1994). Significantly more female mosquitoes were caught resting inside the smoke-free room than the room with smoke. However, there was no significant difference in the proportion of mosquitoes that fed on humans. No experimental studies of the repellent effects of smoke from other biomass fuels were found.

Three observational studies (Barber and Forbich, 1933; Danilov, 1928; Kligler and Mer, 1932), from New Mexico, Central Asia and Palestine, respectively, suggested that smoke from domestic fuel use deterred mosquitoes from resting or hibernating in houses. However, three further observational studies from South and East Africa (De Meillon, 1930; Gibbins, 1933; Symes, 1930) noted that the smoke from domestic fires in traditional houses did not appear to be associated with any reduction in *Anopheles* mosquito numbers. Wilson (1936) also reported no reduction in the numbers of *Anopheles* mosquitoes caught in traditional Kenyan houses without separate kitchens compared with those with a separate kitchen (presumed less smoky). Ghebreyesus et al. (2000) actually reported significantly greater risk of malaria among Ethiopian children living in (presumably smokier) houses without separate kitchens (risk ratio (RR) = 1.35; $P < 0.05$).

3.1.2. Repellent smoke from specific plant materials

Six well designed, experimental field studies were found using human biting or landing rates as the outcome measure to investigate the effects of smoke from a variety of traditional mosquito-repellent plant materials (see Table 1).

The degree to which the materials were repellent varied according to the species of plant and the species of mosquito. However, all of the test plants significantly reduced biting by 21—84%. A further study in Siberia (Rubtzov, 1939) reported reductions of 85—90% in rates of mosquito and black-fly landings on humans carrying smouldering sticks of thyme (*Thymus serpyllum*) compared with unprotected controls.

It is unclear how much of the observed personal protection in these studies was due to the effect of smoke alone and how much was due to specific plant-derived volatiles released through burning specific plants. Thus, the extent to which these results can be generalised to smoke from domestic fuels is not known.

Several observational studies were also identified. However, since people are more likely to employ anti-mosquito practices in contexts where mosquitoes are more numerous and the problem of nuisance biting is more severe, the results of such studies are hard to interpret. A lack of