Smoke and Malaria

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to Indoor Air Pollution Likely to Increase
Exposure to Mosquitoes and Malaria?

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Adam Biran
Mary Cameron
Jeroen Ensink
Jo Lines
Lucy Smith
(in alphabetical order)

London School of Hygiene and Tropical Medicine

World Health Organization

Content

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Abbreviations

An.	*Anopheles*
ARI	acute respiratory infection
B.	*Brugia*
CI	confidence interval
DALY	disability adjusted life year
IAP	indoor air pollution
ITN	insecticide-treated net
LLIN	long lasting impregnated net
P.	*Plasmodium*
RR	risk ratio
s.l.	*sensu lato*
spp.	species
s.s.	*sensu stricto*
WHO	World Health Organization

Summary

Half of the world's population rely on biomass or coal as their primary household fuel source. The smoke produced from burning these fuels indoors presents a major health risk. Much work is being done to develop interventions to reduce levels of indoor air pollution (IAP). However, anecdotal evidence exists for smoke having a repellent effect on mosquitoes. This raises the possibility that interventions to reduce indoor air pollution might increase the risk of malaria and other insect-borne diseases.

Eighty percent of the burden of insect-borne diseases and ninety percent of the resulting deaths are due to malaria and the report therefore focuses on this disease. A literature review was performed to assess the extent of evidence for smoke providing protection from malaria or mosquitoes. Although there is evidence that the smoke from certain plant products contains active compounds that have a repellent effect, no experimental evidence was found for a repellent effect attributable to smoke from domestic biomass fuels. The evidence base was, however, extremely limited, with only one published experimental study found.

Seven early (pre-1940) observational studies were identified relating to the effects of smoke from domestic fuel use. Three of these (none from Africa) suggested that smoke from domestic fires can deter mosquitoes from resting or hibernating in houses. By contrast three African studies reported no effect of cooking smoke on mosquito numbers observed in houses. A fourth African study found no difference in numbers of mosquitoes caught between houses with a separate kitchen and those without (the latter presumed to be less smoky). A recent observational study from Ethiopia actually reported a significantly greater risk of childhood malaria in (presumably smokier) households without separate kitchens. Soot from wood smoke was not found to have any toxic effect on mosquitoes.

Insect vectors show species-specific variation in feeding behaviour in terms of peak biting times and preference for indoor or outdoor feeding. Most of the world's important malaria vector species, including those in Africa where 90% of deaths due to malaria occur, have biting peaks late at night and in the early hours of the morning, outside the likely peak times for fuel use. This means that in Africa the potential for protection against malaria vectors offered by smoke from domestic fuel use would probably be minimal.

Improved household ventilation through the provision or enlargement of eaves spaces has been proposed as one intervention to remove smoke from the domestic environment. On the other hand, eaves spaces have been found to be an important entry point for vector mosquito species and a number of studies have suggested that eaves spaces are associated with higher mosquito densities and an increased risk of malaria. Eaves spaces can to some extent be protected against mosquito entry by the use of screens or curtains. The protection against malaria is increased if the materials used are treated with insecticide. Yet the extent to which effective ventilation is diminished by protecting eaves in this way is not clear.

All of the studies reviewed of the effects of eaves spaces were observational. These studies are liable to confounding and are unable to provide reliable evidence for causal relationships. The evidence base is therefore very weak and needs to be strengthened through well designed intervention trials.

Insecticide-treated bednets (ITNs) are a widely used and effective intervention to prevent malaria transmission. Indoor smoke deposits a layer of soot on the bednet fabric. Based on studies to date, the presence of a sooty layer has no detectable impact on the effectiveness of the insecticide but does increase the frequency with which ITNs are washed. Long-lasting impregnated nets retain their insecticidal properties after repeated washing. Dark-coloured nets may also be worth investigating as a way to minimize washing and reduce the associated loss of insecticide. The removal of smoke from houses is also likely to bring benefits in terms of reduced washing of ITNs.

Bearing in mind the limitations of the evidence base the following conclusions are tentatively drawn. Smoke from domestic biomass fuel use is unlikely to provide significant protection

from malaria and work towards reducing indoor air pollution should continue. The reduction of IAP through improved stoves, cleaner fuels and the use of flues to remove smoke avoids the possibility of increased mosquito entry that has been associated with eaves spaces.

1. Introduction

Biomass fuels, such as wood, dung and crop residues, and coal are the primary household energy source for an estimated 3.2 billion people (WHO 2006). When these fuels are burnt on simple, inefficient stoves their incomplete combustion produces smoke, a mixture of small particles, gases and chemicals which can be harmful to health. When burning takes place in poorly ventilated rooms the occupants can be exposed to levels of indoor air pollution that far exceed recommended guidelines. This is a common scenario in low-income countries, particularly in rural areas where biomass fuels may be readily available free of charge (although costs will still be incurred in terms of the resources devoted to fuel collection).

It is estimated that exposure to indoor air pollution from domestic stoves results in around 1.5 million deaths annually from chronic respiratory diseases and acute respiratory infections (WHO 2002, Smith et al. 2004, WHO 2006). Efforts have been made to address this global health problem. Usually these have focussed on reducing smoke through improved stoves that burn fuels more cleanly and more efficiently and cleaner fuels, or on removing smoke through improved house ventilation, chimneys or flues. Numerous promising interventions have now been developed although widespread dissemination remains a major challenge.

The health risks posed by exposure to indoor air pollution are now widely accepted. However, smoke is also anecdotally claimed to bring a number of benefits. These include improving the flavour of food, preserving timbers and, most importantly from a public health perspective, repelling biting insects. With respect to the latter it is not clear which property of smoke or which specific pollutant may be responsible for such a repellent effect. It is therefore possible that interventions designed to reduce levels of indoor smoke might exacerbate the threat from malaria and other insect-borne diseases.

A number of different mosquito genera are involved in disease transmission and are outlined in Box 1. Eight insect-borne diseases are together responsible for an estimated 1.42 million deaths and 58.5 billion disability adjusted life years (DALYs) lost globally each year (see Table 1) (WHO 2004). Malaria is responsible for 80% of these lost DALYs and 90% of these deaths. Over 1 million children are estimated to die annually from malaria acquired from bites of infected *Anopheles* mosquitoes (Gordon et al. 2004). The main focus of this study is on malaria because of its overwhelming contribution to the burden of vector-borne disease.

Africa is also a principal focus of our study, not only because African communities suffer most of the world's burden of malaria, but also because 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 global child deaths from this risk factor. In the case of malaria, the number of directly attributable child deaths in sub-Saharan Africa has recently been estimated as 790,000, which is more than 90% of the estimated global toll of malaria deaths in children (Bryce et al. 2005).

This study examines the evidence that smoke offers protection from mosquitoes and considers the possibility that interventions to reduce indoor air pollution might increase the risk of malaria. However, it would be an oversimplification to view the relationship as a direct trade-off between ARI deaths and malaria deaths. This is because malaria is also an important indirect cause of child mortality (Molineaux 1997). For example, a child weakened by the chronic effects of malaria may be killed by an episode of pneumonia that would not have been fatal in the absence of malaria. Such events are probably very common in Africa, especially in areas where most people are infected with malaria parasites most of the time, and many children die as a result of multiple infections. Thus it is possible that an intervention to reduce ARI could still be beneficial even if it results in some increase in direct malaria mortality. Unfortunately, interactions of this kind are not well understood, and this uncertainty makes it very difficult to balance expected reductions in one risk against possible increases in another.

The report is divided into four main sections.

- The first considers the evidence that smoke can effectively repel mosquitoes and, in light of what is known about malaria transmission rates, the extent to which smoke has the potential to impact on malaria prevalence.

- The second section looks at the behaviour patterns of insect vectors and the potential for indoor smoke from routine domestic activities to impact on these behaviours if that smoke does have repellent properties.
- The third section explores the possibility that interventions to remove smoke through improved ventilation could result in houses being more penetrable for mosquitoes.
- The fourth section reviews the possible impact of indoor smoke on the effectiveness of insecticide-treated bednets (ITNs). The focus of the report is on malaria, other diseases and their insect vectors are mentioned in passing.

Box 1. The public health importance of mosquitoes (adapted from Service 1993)

There are approximately 3450 species of mosquito. The majority of these pose no threat to public health. However, those capable of transmitting diseases such as malaria, lymphatic filariasis, Japanese encephalitis and dengue fever cause a significant health burden. Malaria is transmitted by mosquitoes of the genus *Anopheles*. Over 420 species of *Anopheles* mosquitoes have been identified of which around 70 are malaria vectors and around 10 are of major public health importance. Lymphatic filariasis is transmitted by over 90 species of mosquitoes belonging to 5 different genera: *Culex*, *Anopheles*, *Mansonia*, *Aedes* and *Coquillettidia* (in descending order of im portance). Mosquitoes of the genus *Culex* also transmit Japanese encephalitis. The vectors of dengue fever belong to the genus *Aedes*.

Table 1. The health burden of vector-borne diseases

Disease	Health burden (WHO 2004)		Geography of disease (Chin 2000)	Insect vectors
	Burden of disease (DALYs)	Number of deaths		
Malaria	46,486,000	1,272,000	Sub-Saharan Africa, Central, South & South East Asia, parts of South America (e.g. Brazil)	*Anopheles* mosquitoes
Lymphatic filariasis	5,777,000	0	*Wuchereria bancrofti* in Africa, Asia, Pacific islands & Latin America; *Brugia malayi* in parts of rural South West India, South East Asia, China South Korea; *B. timori* on islands of South East Indonesia & Timor	Several species of *Anopheles*, *Culex, Aedes*, *Mansonia* mosquitoes
Leishmaniasis	2,090,000	51,000	Parts of Africa, Asia, Middle East, Mediterra-nean, Central Asia & Latin America	*Phlebotomines* (sandflies)
African trypanosomiasis	1,525,000	48,000	Tropical Africa	Several *Glossina* species (tsetse flies)
Japanese encephalitis	709,000	14,000	Asia, Western Pacific islands	Mosquitoes of the *Culex vishnui* group
Chagas disease	667,000	14,000	Central & South America	Various species of Triatomine bugs: *Triatoma*, *Rhodnius*, *Panstrongylus*
Dengue fever	616,000	19,000	Asia, Pacific, Africa, Americas	*Aedes aegypti* (and other *Ae-des* species) mosquitoes
Onchocerciasis	484,000	0	Parts of sub-Saharan Africa & Latin America	*Simulium* flies (black flies)
TOTAL	**58,354,000**	**1,418,000**		

2. Does smoke repel mosquitoes and prevent malaria?

There is anecdotal evidence that smoke is an effective insect repellent, and the practice of 'smoking' rooms to prevent the nuisance of biting mosquitoes is widespread. A nationwide survey in Malawi, for example, found that 64% of households reported burning leaves, wood or dung to produce smoke for the purpose of repelling mosquitoes (Ziba et al. 1994). Several mechanisms to explain how smoke may influence the biting behaviour of mosquitoes have been suggested. Smoke may mask human odours and particularly carbon dioxide, that are detected by mosquitoes during short-range host location (Moore and Lenglet 2004; Moore et al. 2006). By lowering humidity, smoke can interfere with mosquito chemoreceptors that are more responsive in the presence of moisture (Davis and Bowen 1994). In addition, certain plant smokes contain a number of organic compounds that act as irritants, repellents or insecticides (Moore and Lenglet 2004). These include fatty acids such as capric, oleic and palmitic acids (Clay and Clement 1993).

Almost every culture that is exposed to nuisance-biting insects has a tradition of using plant-based repellents, usually from specific plants. Often these plants contain aromatic oils, and in many cases they are burned to make smoke, either directly on charcoal stoves or in specially designed pots (Bockarie et al. 1994; Lines et al. 1987; Moore and Lenglet 2004; Moore et al. 2006; Snow 1987). In The Gambia, for example, *churai* (woods and resins from aromatic trees, mainly *Daniella oliver*) is sold during the rainy season as a mosquito repellent (Snow 1987). In Brazil, the husks from the motaçu palm (*Attalea princeps*, synonym *Scheelea princeps*) serve the same function and are thrown on the fire as a repellent (Sears 1996). These natural plant fumigants are used in a similar way to mosquito coils, their active compounds being volatilized through heat from a cooking fire or hot embers to produce a repellent smoke (Moore 2005). Plant-based essential oils can be heated and used as a repellent in a similar way. The literature relating to the use of these oils is not considered here but has been reviewed by Curtis et al. (1990).

2.1 Methods

A search of published literature was carried out to uncover studies reporting the effects of smoke on mosquitoes and its effectiveness as a form of personal protection against mosquitoes and malaria. A full systematic review was not conducted. The number of databases and search terms used was limited and only English language sources were included. A further limitation of the search strategy is that articles were selected on the basis of title and abstract. This means that risk factor studies of malaria that have included 'smoke' among the risk factors may be missed if the authors did not consider the finding sufficiently important to mention it in the abstract. However, a number of international experts in the field were consulted and it seems unlikely that the search missed any major body of evidence on this specific issue.

The search used the Pubmed database. The 'exposure' terms biomass, burn, combust*, cook*, dung, fire*, indoor air pollution, smoke, stove*, fuel, coal and charcoal were combined with the 'outcome' terms aedes, anopheles*, 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. All articles were selected by title in the first instance and abstracts were read. 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 including Tropical Disease Bulletin, Abstracts of Hygiene and Review of Medical and Veterinary Entomology, and thus covers a large part of the old vector control and tropical hygiene literature that is not included in modern databases and cannot otherwise be searched electronically. Relevant articles were selected on the basis of abstracts and read in full. Additional material also came from the personal collection of one of the authors (M. Cameron) and was identified through discussions with entomologist colleagues at the London School of Hygiene and Tropical Medicine.

2.2 Results

Like Croft (2005), the current search found no randomized controlled trials at community-level, or any systematic reviews on the effectiveness of smoke from wood or plant material to either repel mosquitoes or prevent malaria. There were, however, both experimental and observational studies addressing these questions, some on the effect of domestic fires (mainly for cooking) and some on the effect of plants burned specifically as a repellent.

Smoke from domestic fuels.

One experimental study of the effectiveness of smoke from a domestic fuel (firewood) as a mosquito repellent was found (Bockarie et al. 1994). This study investigated the effect of burning wood (species not given) inside bedrooms of two houses in Sierra Leone. In one bedroom, wood was burned just before the two inhabitants went to bed (around 21.00) and the room was filled with smoke for approximately four hours. In the other room, no wood was burned. Mosquitoes were captured the following morning using exit traps (to collect mosquitoes leaving the rooms) and pyrethrum spray collections (to collect mosquitoes resting in rooms). The experiment was repeated over 15 nights. Blood-meals of engorged mosquitoes in collections were identified.

Significantly more female mosquitoes were caught resting inside the smoke-free room than the room with smoke. Mosquitoes left the smoke-filled room shortly after feeding (perhaps due to reduced humidity levels associated with use of a fire). However, there was no significant difference in the proportion of females that blood-fed on humans between the two rooms. The study concluded that smoke from household fires deterred resting by *An gambiae s.s.* mosquitoes (i.e. reduced endophily) but did not significantly affect the feeding success of mosquitoes on humans (i.e. no change in endophagy). No experimental studies of the effectiveness of smoke from other biomass fuels as mosquito repellents were found.

Three observational studies (Danilov 1928; Kligler and Mer 1932; Barber and Forbich 1933; from Central Asia, Palestine and New Mexico 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; Symes 1930; Gibbins 1933) 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) reported no reduction in the numbers of *Anopheles* mosquitoes caught in traditional Kenyan houses without separate kitchens as compared to those with a separate kitchen (presumed to have a less smoky living/sleeping environment). One observational study in Indonesia suggested that an increase in malaria was associated with a move to modern houses with separate kitchens (Anthony et al. 1992). However it should be noted that the move was also associated with the construction of drainage ditches close to the houses that provided additional breeding grounds for mosquitoes. Furthermore, the scant entomological data and lack of good baseline malaria data make it impossible to draw firm conclusions from this study. Ghebreyesus et al. (2000) actually reported significantly greater risk of malaria among Ethiopian children living in (presumably smokier) houses without separate kitchens (RR=1.35, $P<0.05$). Additionally, lighting fires has been reported as a means of protecting cattle from mosquitoes (e.g. Yanovich 1961) and as a means of producing smoke to drive resting or hibernating mosquitoes to areas of air and light where they can be killed manually (Shapiro 1923; Raevskii 1927). However, these were not studies of ordinary domestic fuel use.

Repellent smoke from specific plant materials.

Eight experimental field studies investigating the effects of smoke from a variety of traditional mosquito repellent plant materials were found. Six of these studies used careful designs and human biting or landing rates as the outcome measure (see Table 2). The degree of personal protection provided by smoke generated from burning plant-based material was obtained by comparing the number of mosquito landings on paired volunteers who received the treatment (a traditional repellent plant smoke) or control (no smoke, charcoal smoke or mosquito coil smoke). The percentage reduction in biting was calculated using the following formula: percentage reduction = [(number of landings in control group – number of landings in treatment group) / number of landings control group)] x 100 (Pålsson and Jaenson 1999a). Various mosquito species were involved, including *Aedes*, *Culex* and *Mansonia* species as well as *Anopheles* malaria vectors. The degree to which the plant materials were repellent varied according to the species of plant and the species of mosquito. Those materials that did significantly reduce biting brought about reductions ranging from 21 to 84%. A further study in Siberia (Rubtzov 1939) reported reductions of 85% to 90% in rates of mosquitoes and black fly landing on humans carrying smouldering sticks of thyme (*Thymus serpyllum*) compared with unprotected controls.

The human bait tests in Guinea Bissau (Pålsson and Jaenson 1999a) were followed up by a further test with some of the same repellents in domestic use in the local village, and measuring the numbers of mosquitoes caught resting in or on untreated mosquito nets (Pålsson and Jaenson 1999b). This confirmed the repellency of smouldering leaves of the basil-like plant *Hyptis suaveolens*, which is traditionally used for this purpose in East as well as West Africa. The researchers then took solvent extracts of some of these plants (including *Hyptis suaveolens*), showed that these were repellent to mosquitoes in the absence of smoke, and found using gas chromatography that they contained a variety of volatile substances known to have mosquito-repellent activity (Jaenson et al. 2006). In the other studies, however, it is unclear how much of the observed personal protection was due to the effect of smoke alone, and how much was due to specific plant-derived volatiles released through burning. Thus, the extent to which these results can be generalized to smoke from domestic fuels is not known.

Observational studies at the household level tend to be much less useful for assessing the effectiveness of anti-mosquito practices, because people are presumably more likely to employ these practices at times and places when the problem of nuisance biting is more severe. Thus, in a house-by-house survey of repellent use and mosquito abundance or malaria, it is not obvious what sort of association should be expected. If the repellents are effective, and if they are used independently of natural variations in mosquito numbers, the expected association is negative. On the other hand, the houses that have more mosquitoes (because of differences in construction or proximity to a breeding site) may also tend to use more repellent and this would produce a positive correlation. The overall outcome is therefore hard to predict.

In practice, all these possibilities have been observed. For example, in Sri Lanka, van der Hoek et al. (1998) found a negative association, in the form of a significantly lower risk of malaria in households using traditional fumigants compared to those which did not (RR 0.58, 95%, CI 0.37 – 0.93). On the other hand, a subsequent study by the same team in a nearby location found that reported use of fumigants and relatively high mosquito densities were positively associated with each other and with proximity to a known breeding site (Konradsen et al. 2003).

Similarly, in West Africa the practice of burning *churai* has been shown to significantly reduce biting of *Culex*, *Aedes* and *Anopheles* mosquitoes (Lindsay and Janneh 1989; Pålsson and Jaenson 1999a). However, a field study to investigate the effects of burning churai on the incidence of malaria in Gambian children where *An. gambiae s.s.* was the main vector (Snow et al. 1998) found no significant association between churai use and any of the measures used (malaria parasitaemia, enlarged spleens, mean packed cell volumes and febrile episodes). It is possible that the reduction in biting offered by churai is insufficient to result in a reduction in malaria, and/or that the degree of personal protection offered by *churai* is species-specific. The latter explanation is supported by the results of a laboratory study performed in 1987, where burning *churai* in clay charcoal burners, as used in The Gambia, did not reduce the feeding success of *An. gambiae s.s.* (C. Curtis and N. Hill personal communication). On the other hand, it is also possible that the use of *churai* was both effective and more common in houses with relatively high levels of mosquito biting nuisance, so that the human occupants of these houses ended up with approximately average levels of exposure to malaria. Thus, the lack of observed association in this kind of household study does not necessarily mean that the repellent was not effective. The same applies to an observational study in Mexico (Danis-Lozano et al. 1999), which found no decrease in risk of malaria associated with the use of unspecified smoke as a repellent. The study used health centre records to identify cases on the basis of reported symptoms and positive results of blood tests for malaria parasites (*P. vivax*). Biting rates were not reported in this study.

Again, it should be emphasized that studies of this kind cannot address the question of whether the protective effect (if any) is provided by plant-specific volatiles within the smoke or by some product of incomplete combustion that is also common to smoke from biomass fuels.

Table 2. Control trials investigating the effect of burning wood or plant-based material on human landing or biting rates.

Reference	Study setting	Plant material	Mosquito species	Mean % reduction in biting versus control (± 95% CI)
Lindsay and Janneh (1989)	The Gambia	*Churai* = *santango* (woods and resins from various species, mainly *Daniella oliveri*) (control = no smoke)	*Culex spp.*	77 (70 - 83)
Vernede et al. (1994)	Papua New Guinea	1) Betelnut leaves *(Areca catechu)* 2) Ginger *(Alpina spp.)* 3) Coconut husks *(Cocos nutifera)* (control = no smoke)	*An. karwari*	1) 84 (62-94) 2) 69 (25-87) 3) 66 (17-86)
Paru et al. (1995)	Papua New Guinea	1) Coffee wood *(Coffea robusta)* 2) Breadfruit *(Artocarpus altilis)* 3) Leucina *(Leucaena leucocephala)* 4) Tulip *(Gnetum gnemon)* (control = no smoke)	a) *Anophelines* b) *Culicines*	a) 76 (50 -88) b) 80 (69-87) (Figures are mean reductions for protected against unprotected individuals. The plant species are not separated in the analyses.)
Pålsson and Jaenson (1999a)	Guinea Bissau	1) *Hyptis suaveolens* 2) *Daniellia oliveri* bark 3) *Azadirachta indica* leaves 4) *Eucalyptus guineensis* infructescences (control = no smoke)	a) *An. gambiae s.l.* (62%) b) *An. pharoensis* (24%) c) *Culex* or *Aedes* (9%) d) *Mansonia* (5%)	1 a-d) 84 (82-89) 2 a-d) 78 (76-85) 3 a-d) 76 (73-82) 4 a-d) 69 (65-77)
Sayoum et al. (2002)	Kenya	1) *Corymbia citriodora* leaves 2) *Hyptis suavelens* leaves and flowers 3) *Lippia uckambiensis* leaves 4) *Ocimum americanum* leaves and seeds 5) *Ocimum kilimandscharicum* leaves and seeds 6) *Ocimum suave* leaves and seeds (control = burning charcoal)	a) *An. gambiae s.s.*	1 a) 51(39, 61) 2 a) 21 (5, 34) 3 a) 33 (16, 47) 4 a) 21 (3, 36) 5 a) 26 (8, 41) 6 a) 28 (3, 34)
Moore et al. (submitted)	Bolivia	1) *Attalea princeps* husks vs charcoal (negative control) 2) *Attalea princeps* husks vs 10mg d-allethrin coil (positive control)	a) *An. darlingi* b) *Mansonia spp.*	1 a) 35 (13-82) 1 b) 51 (37-66) 2 a) 60 (36-84) 2 b) 59 (36-82)

5.3 Malaria transmission

Malaria transmission rates are determined by a number of factors including (but not exclusively): the density of the female mosquito population in relation to humans, the frequency with which female mosquitoes bite humans, the probability of an infected female mosquito surviving long enough for any parasites she carries to mature, the probability of a female mosquito picking up parasites on biting a human and the probability of her passing on mature parasites on biting a human (Molineaux 1998). The dynamic interplay between these factors means that the findings of much conventional epidemiological research on malaria may be context-specific and should be interpreted and extended with caution.

The relationship between exposure to infective bites and the burden of malarial disease is highly non-linear. At the lower end of the transmission intensity scale, where levels of natural immunity to malaria are low, each sporozoite-positive mosquito bite on a person has a more or less constant probability of giving rise to a case of malaria disease. In these circumstances, case incidence rates are highly sensitive to small changes in the exposure of the human population to infective biting, and a modest degree of protection against biting (e.g. reducing indoor mosquito densities by 70%) could in theory give a worthwhile degree of benefit. On the other hand, this magnitude of protection might be hard to detect against the background variation, as mosquito densities naturally fluctuate wildly in both time and space. It is common for biting densities to vary by five-fold or more (a) between neighbouring houses, (b) between neighbouring villages and (c) from one night to the next. The latter point is well-illustrated by the data for one bedroom, shown in Figure 1 below (Smith et al. 1993).

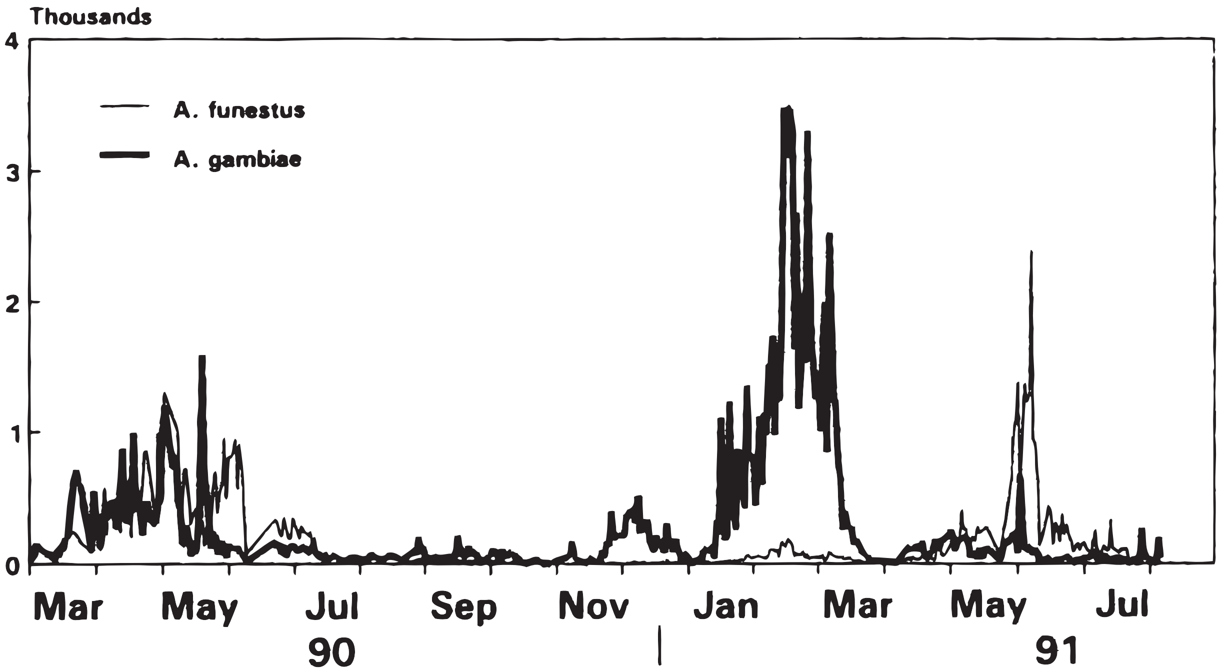
By contrast, in the relatively intense transmission conditions seen in most of sub-Saharan Africa, the incidence of morbidity and mortality due to malaria is far less sensitive to variations in the rate of infective biting (transmission). This is because probability that each sporozoite-positive mosquito bite leads to a new case of malaria. Immunity therefore acts as a negative feedback mechanism that dampens the epidemiological impact of fluctuations in mosquito density. Consider the following approximate and illustrative figures, which are drawn from a variety of vector control field trials carried out over the last decade. In these trials, it was often observed that powerful vector control interventions (e.g. insecticide-treated nets) could bring about substantial — i.e. more than ten-fold — reductions in the rate of infective biting. The impact of this on the incidence of mild malaria episodes was, however, relatively modest: in a typical case, the observed incidence went down by about two-fold following intervention. The observed reductions in cross-sectional prevalence were even smaller, typically declining from a pre-intervention level of around 55% to a post-intervention level of around 45%. Therefore, even if smoke from domestic fuel use typically reduced indoor mosquito biting by 70%, or something of that order, its effects are unlikely to be large enough to be easily detectable in areas of high transmission.

Any reduction in exposure to malaria-infective mosquito biting must always be regarded as desirable, even if it is small, and whether or not it brings about a demonstrable and statistically significant reduction in malaria. However, the above epidemiological considerations suggest that malaria incidence will be sensitive to the marginal effects of smoke only in places where malaria is only an occasional problem. In places where malaria is a constant, everyday and overwhelming problem, the population prevalence of infection tends to be much less sensitive to small changes in exposure. In any case — no matter what the circumstances and the methods of measurement — the beneficial repellent effects of smoke are always likely to be small compared to those of the many other environmental variables, such as temperature and humidity, which cause mosquito biting densities to fluctuate so erratically.

The problem with smoke from domestic fuel use is that any repellent effect that it might have would carry the cost of increasing the risks of acute and chronic respiratory problems. Ideally, the increased risk of respiratory infection from IAP would be weighed against any decreased risk of malaria allowing context-specific guidance as to when (if ever) smoke carries a net health benefit. The lack of good quality data and the complexities of infectious disease epidemiology make it impossible to present such clear-cut empirical guidance here.

The use of residual insecticides (sprayed on interior walls or used to treat bednets) repeatedly exposes female mosquitoes to the risk of death and is therefore potentially a far more powerful tool in malaria control than the use of smoke as a repellent and carries a much lower risk to human health. The need to combat malaria is not a good argument for failing to address the problem of indoor air pollution. This is just as true for Africa, where malaria is the most important cause of child mortality, as it is for other places where malaria is present but has a less significant public health impact.

Figure 1. Variation in mosquito biting densities (Reproduced with permission from Smith et al. 1993)



This graph shows how mosquito biting densities varied in a single bedroom in Tanzania. A light trap catching blood-seeking female mosquitoes was set in the room more or less every night for more than a year. As well as the seasonal trends, which follow the pattern of the rain, there are wildly erratic fluctuations from night to night. Reproduced with permission of Thomas A. Smith, Swiss Tropical Institute, Basel.

3. Do fuel use and vector behaviour coincide in space and time?

Interventions that seek to prevent malaria through vector control need to take into account the behavior of the insect vectors and the at-risk human population. Thus, the effectiveness of residual spraying of house walls with insecticide is dependent on the extent to which mosquitoes rest on indoor walls. Similarly, the effectiveness of insecticide-treated bednets relies on mosquitoes biting primarily during the times that people are in bed (Pates and Curtis 2005). The potential for indoor smoke to impact on disease transmission presupposes that infective contact with the insect vectors takes place indoors during times of combustion. It is therefore of interest to consider what is known about vectors in terms of the timing and location of their feeding behavior. The feeding and resting behaviors of important insect vectors are summarized in Table 4. There is a wide variety of behavior across the different genera and species. Some characteristically bite indoors (endophagic) and some outdoors (exophagic). Similarly, some characteristically rest indoors (endophilic) and some outdoors (exophilic).

If indoor smoke indeed has a repellent effect, the vector species most likely to be repelled are mosquitoes that feed and rest indoors, i.e. *Anopheles* and *Culex* species, responsible for the transmission of malaria and filariasis respectively, and triatomine bugs responsible for the transmission of Chagas disease (American trypanosomiasis) (see Table 4). *Culex* mosquitoes are also largely responsible for so-called nuisance biting, often an important factor in influencing behaviours to repel mosquitoes (Thomson et al. 1996).

Timing of biting may also be critical in determining whether blood-feeding is interrupted by smoke from domestic fires. The timing and duration of fuel use will vary locally, seasonally and also between households depending on cooking practices and the need for space heating. Many households have a fire burning in the early morning and early evening for cooking the main family meals and, depending on climatic conditions, heating (Albalak et al. 1999; Barnes et al. 2004); some may also cook during the day if not all of the family members are out working (Wafula et al. 1990). Cooking activities are associated with peaks of smoke production (Ezzati et al. 2000). A common (though not necessarily universal) feature of domestic fuel use is that throughout most of the night cooking activities cease and smoke production is therefore greatly reduced if not absent altogether. From observations of energy-related behaviours in rural South Africa, the last fuel use activity of the day was around 19.30 after which the fire was left to burn out (Barnes et al. 2004). In contrast, in Kenya, the stove was burning until 20.00 (Ezzati et al. 2000).

Gillies (1988) reviewed the biting cycles of a variety of vector and non-vector *Anopheles* species, from Africa, Asia and Latin America, and pointed out that the peak-biting times of epidemiologically important vectors tends to be late at night (after midnight), while the non-vector species mostly have either an early-evening peak or more or less constant levels of biting activity throughout the night. A more recent review of this question (Pates and Curtis 2005) concluded that more than 75% of anopheline bites by the most efficient anthropophilic vector species occurred between 22.00 and 05.00, which is assumed to be the time when most people in rural areas are in bed. This was found for the important malaria vectors *An. gambiae*, *An. funestus* and *An. nili* in Africa, *An. dirus* and *An. minimus* in South-East Asia and *An. anthropophagus* in China. Studies by Bockarie et al. (1994) in Sierra Leone and Papua New Guinea also reported late night biting habits for *An. gambiae* and *An. punctulatus* respectively. Furthermore these authors found that a greater percentage of mosquitoes biting after 22.00 were older parous females, which are more likely to carry large numbers of sporozoites in their salivary glands (increasing infectivity). Before 22.00 a greater percentage of biting mosquitoes were nulliparous females, too young to carry developed sporozoites. Githeko et al. (1996) also report that biting by *Anopheles* mosquitoes in Kenya peaks after 22:00 while over 90% of villagers retire to bed by 21:00.

It might be suggested that the late night biting pattern observed is a result of household environments being smoky earlier in the evening. However, the review by Pates and Curtis (2005) is more suggestive of species-specific biting patterns than of a general trend for vectors to avoid the earlier evening. Furthermore, the review includes data collected outside houses which would not be affected by indoor air pollution levels.

Thus it seems likely that the majority of malaria transmission in sub-Saharan Africa, although it occurs indoors, takes place at times when smoke production is expected to be minimal. Therefore, it is unlikely to be affected by interventions reducing the quantity of indoor smoke. This possible general pattern is, however, based on minimal data and likely to be subject to local variation. In other geographical areas the behaviour of malaria-transmitting mosquitoes may differ. For example, during the cold season in Pakistan *An. culicifacies* tends to bite before 20.00, a time when families may be using fires for cooking and warmth. Likewise in Central America, much of the biting by *An. albimanus* occurs before 22.00, however, this tends to take place outdoors.

Table 3. Vector behaviour [1]

Insect group	Diseases transmitted	Biting behaviour		Insect vectors
		Time of biting	Location of biting	
Anopheles (mosquitoes)	Malaria, filariasis	Most anophelines have a late-night biting tendency (exceptions: cold weather in South Asia, Central America, Brazil).	May bite inside or outside dependent on species.	Rest indoors or outdoors depending on species.
Aedes (mosquitoes)	Dengue fever, dengue hemorrhagic fever, filariasis in Polynesia	Tend to bite in the morning or evening.	Mostly feed outdoors.	Rest outdoors.
Culex (mosquitoes)	Bancroftian filariasis	Tend to bite at night.	Feed both indoors and outdoors.	Rest during the day indoors or outdoors on vegetation.
Mansonia (mosquitoes)	Brugian filariasis	Usually bite at night.	Mostly feed outdoors but occasionally enter houses.	Mostly rest outdoors.
Phlebotomines (sandflies)	Leishmaniasis	Normally bite at night; only bite during day when disturbed.	Most species feed outdoors.	Mostly rest outdoors.
Glossina (tsetse flies)	African trypanosomiasis (sleeping sickness)	Usually bite during the day (attracted to hosts by olfactory and visual cues).	Feed outdoors.	Rest outdoors.
Simulium (black flies)	Onchocerciasis (river blindness)	Peak of biting usually in morning and afternoon.	Feed outdoors.	Rest outdoors.
Triatomine bugs	Chagas disease (American trypanosomiasis)	Most triatomines are nocturnal.	Feed on sleeping inhabitants inside houses.	Rest indoors, often hiding in firewood piles.

[1] Adapted from Lane and Crosskey (eds) (1993) and Leak (1999).

4. Does increased ventilation (eaves spaces and windows) increase the risk of malaria?

The interventions proposed to reduce levels of indoor air pollution can be divided into those that reduce pollution at source, and those that aim to remove pollution from the household environment (WHO 2000). Interventions among the latter include the installation or repositioning of windows and the creation or expansion of eaves spaces (WHO 2006).

Studies of house-entering habits of mosquitoes in The Gambia have shown that endophagic mosquito species, such as *An. gambiae*, *An. melas* and *Mansonia* spp., fly upwards when they make contact with a vertical wall and enter the house through eaves spaces; on the other hand, more exophilic species such as *An. pharoensis* and *Aedes* spp. are less able to do so and are progressively excluded with increasing wall height (Snow 1987). This trait of flying upwards means that eaves spaces are one of the major routes whereby *An. gambiae* (the most important malaria vector species in Africa) enter houses.

This section considers the possibility that efforts to reduce indoor air pollution through increased house ventilation may lead to increased numbers of anopheline mosquitoes entering the household, thus increasing risks of malaria transmission.

4.1 Methods

The literature relating to household construction, ventilation and malaria transmission was reviewed. The Pubmed database was searched using the 'exposure' terms, house construction, eaves and window* and the 'outcome' terms aedes, anopheles*, culex*, culicidae, malaria*, mosquito*, ochlerotatus, vector*, vector-borne, bite, biting, blood meal, feeding behavior, feeding pattern*, resting behavior 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 were selected on the basis of abstracts and read in full.

4.2 Results

The results of the literature search are reported in Tables 4 and 5. Homes with open eaves spaces have been shown to have larger numbers of mosquitoes compared with those without eaves spaces as summarized in Table 4. With the exception of Adiamah et al. (1993), which found mixed results, and Lindsay et al. (2003), which narrowly missed statistical significance, all of the studies identified indicate significantly reduced indoor anopheline populations associated with the absence of open eaves spaces. Anopheline numbers were 10 to 60% lower in homes without eaves spaces compared to homes with open eaves spaces.

Reduced mosquito numbers inside houses could possibly reduce transmission of malaria. A number of epidemiological studies have indeed shown significant associations between the presence of closed eaves spaces and a decreased risk of malaria as summarized in Table 5. Ratios of malaria risk for those living in houses with closed eaves spaces compared to those living in houses with open eaves spaces ranged from 0.36 (95% CI 0.18-0.74) to 0.54 (95% CI 0.35-0.84). Two of the studies found (Adiamah et al. 1993; Snow et al. 1998) did not support these findings. Snow et al. (1998) suggested a reduced risk for those living in houses with closed eaves spaces in Kenya but the results were not significant after adjustment for confounders using a regression model. Adiamah et al. (1993) found an increased risk of malaria in those living in houses with closed eaves spaces but this increase was not statistically significant.

Only one study was identified that investigated the effect of windows on risk of malaria. Ghebreyesus et al. (2000) reported an increased risk of malaria among highland Ethiopian children living in houses with windows (RR=1.87, $P<0.05$).

Confounding is an important factor for consideration in these studies, since with the exception of Lindsay et al. (2003) they are observational. In any one community, the presence of open or closed eaves is usually closely associated with other structural variations, including construction materials, ceilings and window size, which might also affect by access and attractiveness to mosquitoes. In order to be able to draw strong conclusions about the causal links between open eaves spaces and malaria transmission carefully designed intervention studies will be needed.

A number of studies have shown that eaves spaces as well as open windows and doors can be protected to some extent against mosquito entry by using curtains or screens (see reviews by Greenwood 1999 and Lindsay 2002). Fanello et al. (2003), for example, showed that indoor anopheline mosquito populations could be reduced by around 50% through the use of untreated curtains over windows, doorways and eaves spaces and that this increased to 85% when the curtains were treated with carbosulfan insecticide.

Significant reductions in malaria morbidity have also been found associated with the use of insecticide-treated curtains. An insecticide-treated curtain intervention in Kenya reduced indoor biting rates of the two major vectors *An. gambiae* and *An. funestus* by 76% and resulted in a 17% reduction in mean malaria prevalence in children (Oloo et al. 1996). Habluetzel et al. (1997) found a 15% reduction in all-cause mortality in young children in Burkina Faso through the use of insecticide-treated curtains. A long-term follow-up study in this population (Diallo et al. 2004) showed sustained reductions in risk of all-cause mortality of around 20% (RR=0.81-0.76). Importantly, there is also evidence that curtains are an easily accepted intervention due to their improvement of the aesthetics of the household (e.g. Majori et al. 1987). However, Croton and Crowden (1955) noted that cotton netting resulted in a 70% reduction in air flow. Further studies would therefore be necessary to determine the extent to which ventilation is affected by curtains of different materials.

Table 4. The impact of eaves spaces on indoor mosquito density [2]

Study site	Mosquito species	Subjects	Sampling method	% change in mosquito numbers with closed eaves spaces	P value	Reference
Farafenni, The Gambia	*An. gambiae s.l.*	All houses	Spray catches	-43.2	<0.02	(Lindsay and Snow 1988)
The Kombos, The Gambia	*An. gambiae s.l.*	Houses of mild malaria cases*	Light traps	-50.0	<0.05	(Adiamah et al. 1993)
The Kombos, The Gambia	*An. gambiae s.l.*	Houses of severe malaria cases**	Light traps	-60.0	<0.001	(Adiamah et al. 1993)
The Kombos, The Gambia	*An. gambiae s.l.*	Houses without any malaria cases (controls)***	Light traps	+43.0	0.3 (n.s.)	(Adiamah et al. 1993)
The Kombos, The Gambia	*An. gambiae s.l.*	Houses without severe malaria cases (controls)***	Light traps	-11.0	0.7 (n.s.)	(Adiamah et al. 1993)
Saruja, The Gambia	*An. gambiae s.l.*	All houses	Bednet catches	-10.0	0.048	(Lindsay et al. 1995)
Riboque, Sao Tome	*An. gambiae*	All houses	Light traps	Not specified†	-	(Charlwood et al. 2003)
Wali Kunda, The Gambia	*An. gambiae*	All houses	Exit traps	-36.9	0.057	(Lindsay et al. 2003)
Bissau, Guinea-Bissau	*An. gambiae s.l.*	All houses	Resting collections	Not specified‡	-	(Pålsson et al. 2004)
Kataragama, Sri Lanka	*An. culicifacies, An. subpictus*	All houses (wet season)	Spray catches	-43.0	<0.05	(Gamage-Mendis et al. 1991)
Kataragama, Sri Lanka	*An. culicifacies, An. subpictus*	All houses (dry season)	Spray catches	-48.7*	<0.05	(Gamage-Mendis et al. 1991)

* Mild malaria cases defined as those infected with malaria parasites, with or without a clinical episode.

** Severe malaria cases defined as cerebral malaria or severe anaemia, with parasitaemia.

*** Mild malaria controls (no malaria) matched with mild malaria cases; severe malaria controls (no malaria) matched with severe malaria cases.

† Number of *An. gambiae* caught in light traps reported to be positively associated with the presence of an eaves gap (P=0.0032), actual numbers not specified.

‡ Percentage reduction in mosquito numbers not given, although chi-squared test showed numbers of mosquitoes in houses with open eaves spaces were significantly higher than in those with closed eaves spaces (X^2 = 48.63, P<0.0001)

n.s. = not significant

[2] Adapted from Lindsay et al. (2002).

Table 5. The impact of closed eaves spaces on malaria morbidity[3]

Study site	Subject group	Type of study	Number of subjects	% of subjects' houses with closed eaves spaces	RR / OR (95% CI)	P value	Reference
Farafenni, The Gambia	Mild malaria cases	Ecological	63	4.6	RR=0.36 (0.18-0.74)	<0.05	(Lindsay and Snow 1988)
The Kombos, The Gambia	Mild malaria cases	Case control	253	25.3	OR=1.11 (0.72-1.69)	n.s	(Adiamah et al. 1993)
The Kombos, The Gambia	Severe malaria cases	Case control	268	23.1	OR=1.35 (0.73-2.48)	n.s	(Adiamah et al. 1993)
Kilifi, Kenya	Mild malaria cases	Case control	760	10.4	OR=0.67 (0.31-1.45)	n.s	(R. W. Snow et al. 1998)
Kilifi, Kenya	Severe malaria cases	Case control	787	10.3	OR=0.70 (0.20-1.16)	n.s	(R. W. Snow et al. 1998)
Tigray, Ethiopia	Severe malaria cases	Cohort	2114	84.0	RR=0.54 (0.35-0.84)	<0.05	(Ghebreyesus et al. 2000)
Grau Region, Peru	Mild malaria cases	Case control	1288	16.9	OR=0.53 (0.36-0.80)	<0.01	(Guthmann et al. 2001)
Kataragama, Sri Lanka	Mild malaria cases	Cohort	3023	74.2	RR=0.50	<0.01	(Gamage-Mendis et al. 1991)
Kataragama, Sri Lanka	Mild malaria cases	Cohort	1875	31.9	RR=0.40 (0.34-0.46)	<0.001	(Gunawardena et al. 1998)

* n.s. = not significant

[3] Adapted from Lindsay et al. (2002).

5. Does soot from domestic smoke impact on the effectiveness of insecticide-treated bednets?

The use of ITNs has been established as an effective intervention against malaria (e.g. Lengeler 2004). When ITNs are used in a smoky environment a layer of soot accumulates on the net which might diminish its effectiveness. However, even substantial accumulations of soot on treated netting have been found to have no detectable impact on the effectiveness of the insecticide (e.g. Curtis et al. 1990). These findings led to speculation that insecticide might be absorbed into the sooty layer with the result that washing a sooty net might remove more insecticide than washing a soot-free net. Further investigation has shown that this is not the case (Kayedi et al. in press).

Nevertheless sooty nets are perceived as dirty and this can increase the frequency with which nets are washed. Washing ITNs decreases the amount of insecticide remaining on them and therefore decreases the effectiveness with which they kill mosquitoes. Washing practices and the perceptions of bednet users need to be understood and accounted for in recommendations for the treatment and re-treatment of nets with insecticide (Miller et al. 1999). The possibility of using darker coloured nets which may reduce washing frequency is another option to be investigated (Gyapong et al. 1996; Kroeger et al. 1997). In most places, there are local preferences for colour, and these may vary between households. Long lasting impregnated nets (LLINs) have also now been developed and two of these (the Olyset and the Permanet) have been approved by the World Health Organization (Roll Back Malaria Partnership 2004). These nets are designed to withstand repeated washes while maintaining their insecticidal properties (N'Guessan et al. 2001; Tami et al. 2004; Graham et al. 2005; Dabire et al. 2006). Nevertheless, given that conventional ITNs are more prevalent than LLINs and that even the performance of LLINs may ultimately be compromised by repeated washing, a reduction in indoor air pollution might have beneficial effects on malaria control by allowing ITNs to remain unwashed for longer periods. The need to wash clothes less frequently is cited by women as one of the advantages of reduced indoor air pollution (L. Bates personal communication) so there is good reason to believe that the same would apply to bednets.

Soot from domestic wood fires has been found non-toxic to mosquitoes although it has been found to prolong the effectiveness of residual insecticide applied to mud walls, presumably by sealing the mud and preventing absorption of insecticide beneath the surface of the wall (Bar-Zeev et al. 1966).

6. Conclusions and recommendations

6.1 Main findings

One of the important findings from this study is the dearth of literature relating to the effects of smoke from domestic fuel use on mosquito behaviour. The conclusions and tentative recommendations presented with respect to this are therefore grounded in a very weak evidence base. Furthermore it should again be noted that the focus of this review was on Africa. Vector behaviour and malaria epidemiology vary across geographical settings making it unlikely that a single rule describing the relationship between smoke, vectors and the incidence of vector borne disease would have global applicability. Keeping this in mind, the main findings of the study are listed below:

- Smoke from domestic fuel use probably does not have much effect on mosquito feeding, but mosquito feeding is affected by smoke from certain plant products traditionally used as repellents.
- The primary biting time for the world's most important malaria vectors is late at night when cooking activities are likely to have ceased.
- The presence of eaves spaces makes houses more permeable to mosquitoes and has been associated with an increased risk of malaria in observational studies in some contexts. Eaves spaces, as well as doors and windows, can be protected to some extent against mosquito entry by using screens or curtains. The protection is increased if these are treated with insecticide. However, the extent to which such measures compromise ventilation is not known.

6.2 Research needs

The evidence base relating to the effectiveness of smoke from biomass fuels for repelling insects and preventing disease is inadequate. It should be relatively straightforward to strengthen this evidence through a series of well designed experiments and intervention studies. Questions that need to be addressed include the following:

- What effect does smoke from different biomass fuels (wood, dung, crop residue, charcoal) or coal have on the feeding behaviour of mosquitoes and other insect vectors? Are such effects limited to certain levels of smoke at specific times of day? How do such impacts vary between indoor and outdoor locations?
- What effects do eaves spaces and other aspects of housing design, particularly those affecting ventilation and light, have on malaria-transmitting mosquitoes and other insect vectors? A randomized controlled trial of eaves spaces with malaria and acute lower respiratory infections as outcome measures could shed more light on the efficacy of this intervention.
- What, if any, are the health risks associated with burning mosquito-repellent plant materials and plant-based essential oils? What levels of exposure to smoke for what duration and in which population segments result from the use of burning these materials?
- What effect does soot have on the frequency and intensity of washing insecticide-treated bednets?
- Does the use of netting to protect eaves spaces from mosquito entry prevent the effective escape of smoke through these spaces?

Qualitative research would also be useful to investigate the health and nuisance perceptions held with regard to smoke and mosquitoes as well as the non-health benefits that may motivate people to reduce their exposure to these risk factors.

6.3 Recommendations

Biomass smoke is known to be harmful to health. There is some evidence that the traditional use of some aromatic plants which are burned to repel mosquitoes can be effective. However, there is no evidence that smoke or soot from routine cooking repels mosquitoes or prevents malaria, and according to some reports published prior to 1940, the presence of cooking smoke has no effect on indoor abundance of African malaria vectors.

In any case, under normal conditions of domestic fuel use, most cooking will be done outside of the peak biting times for malaria vectors.

On this basis there seems to be a good health argument for continuing efforts to reduce indoor air pollution, even in areas where malaria is endemic. It is extremely likely that such efforts will have substantial health benefits in reducing respiratory disease, and extremely unlikely that the reduction of smoke per se will have any significant health costs in terms of increased malaria.

However, interventions that seek to change stove or fuel types may need to take into account any existing insect repellent practices that may give effective protection against mosquitoes (such as burning specific, repellent plant materials) although it must be borne in mind that we know very little about the health risks associated with these practices.

Interventions that seek to remove smoke through increased eaves spaces probably run the risk of increasing mosquito densities inside houses. It would seem prudent to take steps to avoid this risk through the use of netting or curtains over additional windows and eaves spaces. However, the extent to which this would reduce effective ventilation is not known. Using flues, hoods and chimneys to reduce indoor smoke is unlikely to carry the same risk.

The use of insecticide-treated bednets is known to be very powerful as a means of protection against malaria (Lengeler 2004) and, unlike smoke, carries little or no health risk. Even untreated nets are partially effective. Bednets and net treatment should therefore continue to be vigorously promoted. The effective promotion of insecticide-treated bednets in combination with the removal of indoor air pollution would address two major health problems and there may be benefits in taking a more holistic approach to household environmental health.

The main recommendation arising from this study is therefore to continue to promote interventions to reduce indoor air pollution particularly through the use of improved stoves and cleaner fuels, even in areas where malaria is endemic.

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