Commentary: Does a mosquito bite when no one is around to hear it?

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Recent declines in malaria-related morbidity and mortality in Africa have been attributed in part to the widespread scale-up of measures for malaria control, including insecticide-treated bednets (ITNs) and indoor residual spraying (IRS). The percentage of households owning an ITN has increased from 3% to 50% in the past decade, and the number of households protected by IRS has more than quintupled during this same period, reaching 11% of the population at risk. Both ITNs and IRS are particularly effective at reducing the transmission of malaria because they exploit the indoor (endophagy) and nighttime (nocturnality) biting and indoor resting (endophily) characteristics of the most efficient African *Anopheles* malaria vectors. In this way, ITNs and IRS provide both direct personal protection against infective mosquito bites as well as indirect community protection resulting from overall decreases in mosquito abundance.

There has long been concern that deployment on a scale as grand as the roll-out of ITNs and IRS in Africa could promote the development of insecticide resistance as well as behavioural changes among *Anopheles* spp. mosquitoes, eventually undermining the continued effectiveness of ITNs and IRS. It is now increasingly evident that the accelerating target-site and metabolic resistance to pyrethroid insecticides found in malaria vector populations throughout Africa is in large part the result of efforts at malaria vector control. Whereas there are definitive examples of the ways in which insecticide resistance has adversely affected IRS programs, the impact of pyrethroid resistance on the effectiveness of ITNs for malaria control is not yet clear. Documented instances of changes in the vectors host seeking behaviours attributable to ITNs and IRS have resulted in increased outdoor biting and shifts in peak biting times, leading to concerns that these changes could allow transmission of the disease to be maintained even after ITNs or IRS have been fully scaled up.

However, Bernadette Huho and colleagues at six rural sites in Africa (two in West Africa, three in...
East Africa, and one in southern Africa), in an article in this issue of the IJE, remind us that human behaviour is as important as mosquito behaviour in determining when and where malaria transmission occurs. Assessment of the risk of infective mosquito bites must take into account human presence; a voracious mosquito is not even a whiny nuisance when there is no one around to hear it. Although the question of whether there are documented instances in which ITNs or IRS have selected for genetically distinct subpopulations of Anopheles spp. that preferentially bite outdoors or during early evening or late morning hours remains under investigation, there is no suggestion that ITNs or IRS have affected human indoor resting patterns. When biting densities are combined with information from human populations about where members of these populations spend time from early evening to dawn, it is clear that the vast majority of human exposure to biting Anopheles spp. mosquitoes occurs indoors even after vector-control interventions that target endophilic and endophagic mosquitoes have been introduced. Although the results of the study by Huho et al. are good news for malaria-control programs that rely almost exclusively on ITNs and IRS for vector control, several authors have suggested that even a small proportion of exposure to infective bites out of doors (estimated at 11% across the six sites in Huho and colleagues’ study) could pose a significant impediment to malaria control. Target product profiles needed to reduce this fraction of bites have been developed, and there is ongoing research on a variety of approaches that would reduce outdoor biting, including larviciding and odor-baited traps. However, on the basis of the results presented by Huho et al., it could be argued that the extent of the indoor transmission of malaria that is not prevented by ITNs or IRS is sufficient to make the malaria-control community as concerned about residual indoor biting as about residual outdoor biting. Exposure to infective bites indoors occurs during hours when people are inside but not under ITNs (a percentage estimated by Huho et al. to range from 5%–13% at the two study sites at which information about sleeping times was collected). Additionally, other factors, such as nets inadequately tucked in, declining insecticide concentration, and holes or tears in nets, will increase exposure to infective mosquito bites during the sleeping period. Moreover, IRS provides incomplete protection from indoor biting because mosquitoes may not encounter insecticide sprayed onto walls until after they have taken a blood meal. Added to this is that decay of the insecticide in IRS can occur over a period of weeks or months, thus reducing the impact of IRS on mosquito mortality or on deterring mosquitoes from entering into houses. Durable insecticide-treated wall liners, house screening, cave coverings, drop ceilings, and indoor spatial repellents could address the residual indoor transmission of malaria although their modes of action, and any potential antagonistic interaction of these disease-control measures with ITNs and IRS should be carefully considered and monitored.

As we work to ensure that the transmission of malaria continues to decline across Africa, transmission of the disease will become more focal and heterogeneous in time, place, and person. The malaria-control community will need continuously to re-evaluate the settings in which the risk of malaria transmission is greatest so as to select the most effective interventions against the disease as well as to develop the target characteristics of new interventions. However, malaria can be transmitted only when and where mosquitoes bite humans, and the characteristics of both populations will need to be considered to correctly assess the continued ability of vector-control measures to prevent malaria.

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