VOLUME 78, NUMBER 12, 2000, 1374–1491

BULLETIN 2000 This month's special theme: ▶ Malaria ◀

Bulletin
of the World Health Organization

The International Journal of Public Health

Editorial

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Comparison of house spraying and insecticide-treated nets for malaria control

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The efficacies of using residual house spraying and insecticide-treated nets against malaria vectors are compared, using data from six recent comparisons in Africa, Asia and Melanesia. By all the entomological and malariological criteria recorded, pyrethroid-treated nets were at least as efficacious as house spraying with dichlorodiphenyltrichloroethane (DDT), malathion or a pyrethroid. However, when data from carefully monitored house spraying projects carried out between the 1950s and 1970s at Pare-Taveta and Zanzibar (United Republic of Tanzania), Kisumu (Kenya) and Garki (Nigeria) are compared with recent insecticide-treated net trials with apparently similar vector populations, the results with the insecticide-treated nets were much less impressive. Possible explanations include the longer duration of most of the earlier spraying projects and the use of non-irritant insecticides. Non-irritant insecticides may yield higher mosquito mortalities than pyrethroids, which tend to make insects leave the site of treatment (i.e. are excito-repellent). Comparative tests with non-irritant insecticides, including their use on nets, are advocated. The relative costs and sustainability of spraying and of insecticide-treated net operations are briefly reviewed for villages in endemic and epidemic situations and in camps for displaced populations. The importance of high population coverage is emphasized, and the advantages of providing treatment free of charge, rather than charging individuals, are pointed out.

Keywords: insecticides, administration and dosage; malaria, prevention and control; comparative study; evaluation studies; Kenya; Nigeria; United Republic of Tanzania.

Bulletin of the World Health Organization, 2000, **78**: 1389–1400.

Voir page 1397 le résumé en français. En la página 1398 figura un resumen en español.

Introduction

In the 1940s–60s, spraying the inside surfaces of houses with a residual insecticide, principally dichlorophenyltrichloroethane (DDT), was the main means by which the incidence of malaria was reduced to zero, or near zero, in regions where malaria was endemic (*1*). However, mainly because of the declining ability or willingness of governments or donors to continue funding the spraying programmes on a sufficient scale, there has been a resurgence of malaria, though so far not to the levels of the 1930s. In the last 15 years the use of residual pyrethroids to treat bednets has become more fashionable than house spraying as a means of controlling malarial vectors (*2*). It might be expected that insecticide-treated nets would be more effective than house spraying for the following reasons: first, most anophelines bite indoors late at night and bednets thus intercept mosquitoes as they approach sleepers in search of blood (the nets may be considered insecticidal traps baited with the odour of the sleeper inside). By contrast, if walls and ceilings are sprayed, some *Anopheles* species may not rest there long enough to pick up a lethal dose of insecticide; irritant insecticides, such as DDT, may even shorten the resting time on the sprayed surface. Secondly, in many countries there is a tendency to re-plaster mud walls as soon as they have been sprayed (*3*), thus covering up the insecticide deposit.

On the other hand, for insecticide-treated nets to be fully effective, active involvement of community members may be required to make sure that nets are used, even during seasons when their use is uncomfortably hot and there may not be enough biting by nuisance insects to make net use seem worthwhile, though there may still be enough vectors to be dangerous. Community members must also make sure that people, especially children, go to bed before vectors start biting and do not get up before they stop. Finally, nets must be kept in good repair, hung carefully and brought out for re-treatment when required. By contrast, the only requirement of householders for spraying to be effective is that they do not refuse admission to spray teams. After that no further attention by the householder is required for an insecticide deposit on a wall or ceiling to continue to do its job.

To try to assess where the balance of advantage lies, we reviewed data from the best-documented spraying projects conducted in the 1950s–70s, and

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Ref. No. **00-0809**

from some of the best-documented recent insecticide-treated net projects in comparable ecological situations. We have also reviewed six recent side-by-side comparisons of projects using insecticide-treated nets or spraying. The projects we reviewed did not all collect data on the same parameters by the same methods but, where available, we have tabulated their data on the following: the mosquito vector densities in the community; blood feeding in treated rooms; the sporozoite rates; the incidence of new infections; the prevalence of infections (i.e. "parasite rates"); the prevalence or incidence of fever with specified minimum levels of malaria parasites (mild malaria attacks or, in one case, hospitalized cases of severe malaria); haemoglobin concentrations or anaemia; and infant or child mortality due to all causes (Tables 1–3).

Where possible, data taken after interventions were introduced are linked by arrows with pre-intervention data from the same areas (see Tables 1–3). Where contemporary data were collected from untreated control areas, these are placed side-by-side in the tables with data from treatment areas. Thus, one can assess in several of the cases whether the apparent effects of treatments could actually have been due to natural variation between areas or years. In a few cases, where there seem to have been delays before the full effects of interventions were seen, further arrows are used to link the short-term and longer-term effects.

Review of the trials

East Africa

Table 1 shows data from lowland areas of the United Republic of Tanzania which initially were hyper- or holo-endemic for malaria. The first two examples summarize earlier classic success stories of house spraying in tropical Africa, many of which are reviewed by Kouznetsov (*4*). Column 1 shows the Pare-Taveta scheme along the United Republic of Tanzania–Kenya border using dieldrin spraying over a four year period (*5*). Column 2 shows available information from the operational control in the islands of Zanzibar and Pemba from 1958–68 (*6*). Both projects reduced the population of *Anopheles funestus* to undetectable levels, and it was years after the spraying stopped before this important vector species re-appeared. *An. gambiae s. l.* remained detectable, presumably because these mosquitoes (especially *An. arabiensis*) are less exclusively endophilic than *An. funestus,* and therefore some escaped killing by insecticide residues indoors. The prevalence of parasites in infants was reduced by both projects to less than 5%, levels that have not been approached by any of the insecticide-treated net projects in highly endemic areas.

Haemoglobin levels were monitored in the Pare-Taveta scheme and showed a mean rise of about 1.9 g Hb/dl. A reduction in the percentage of outpatients positive for the malaria parasite was recorded at health facilities in Zanzibar. In the Pare-Taveta scheme, mortality of all age groups was approximately halved during the spraying. A follow-up study over subsequent years showed no sign of over-compensatory "rebound", which in the 1950s was already feared might occur as normal levels of immunity faded in areas where malaria had been endemic. After termination of the spraying programme in Zanzibar in 1968, malaria has returned to its original holoendemic level. By the 1980s, when an attempt was made to revive the successes of the original DDT spraying programme, resistance was found in *An. gambiae s.s.* and to a lesser extent in the more exophilic *An. arabiensis* (*7*). This had not been detected during the 1960s and perhaps resistance had been selected by the decaying residues of the original programme.

Table 1, column 3 shows data from a trial of insecticide-treated nets near Bagamoyo (*8*), in which a system of village bednet committees ensured compliance, at least for the duration of the trial, even though the nets and insecticide had to be paid for by householders. The insecticide-treated nets have a substantial impact on both parasite prevalence and anaemia (measured by packed cell volume). It is not easy to compare these results directly with those of the above-mentioned spraying trials, however, because in Bagamoyo the initial parasite prevalence was much higher and a different method of measuring anaemia was used.

A comparative trial was carried out on the use of lambdacyhalothrin for net treatment or for house spraying in 12 villages near Muheza, in the Tanga region (Table 1, column 4; *9*). Both forms of vector control were provided free of charge and consequently there was almost 100% population coverage. In all of the villages, when light traps in rooms with untreated nets were compared with those in treated rooms, there was a substantial and similar reduction in vector populations as a result of either intervention. *An. funestus* was a minority in the vector population and though it was reduced, it was not eradicated during a one year post-intervention evaluation. This is in contrast to the results obtained with the longer-term spraying programmes mentioned above. There was also a significant reduction in sporozoite rates throughout the treated communities, consistent with the results of two other insecticide-treated net trials in this area (*10, 11*). The numbers of blood-fed anophelines in rooms with insecticide-treated nets or which had been sprayed (measured in exit traps on the windows) were far fewer than in rooms in the untreated villages. This partly reflects the reduced mosquito populations in treated villages, with an additional component due to the personal protection provided by the interventions (*12*). As might be expected, the results suggest that nets were more effective in providing personal protection, but the difference in numbers of blood-fed mosquitoes in netted and sprayed rooms was not statistically significant.

Table 1. **Data on four spraying or insecticide-treated net projects in lowland areas of the United Republic of Tanzania**

	Location and dates of study						
	1. Pare-Taveta **1955–59** (*5*)	**2. Zanzibar and Pemba** **1958–68** (*4, 6*)	**3. Bagamoyo** **1992–93** (*8*)		**4. Muheza, Tanga** **1995–96 and 1999** (*9*)		
Treatment/ control areas	Dieldrin spray	DDT spray	Permethrin-treated nets	Control villages	Lambdacy-halothrin-treated nets	Lambdacy-halothrin spray	Control villages
Impact on vector populations	*An. funestus* eliminated	*An. funestus* eliminated	no data		*Light trap catches in rooms with untreated nets*		
					1996: 5.38[a]	3.72[a]	13.37[b]
	An. gambiae s.l. population reduced sevenfold	*An. gambiae s.l.* remained present			*Blood- fed mosquitoes in rooms and exit traps*		
					1996: 0.051[a]	0.080[a]	0.773[b]
	Sporozoites undetectable				*Sporozoite rate (%)*		
					1996: 0.99[a]	1.02[a]	3.92[b]
Incidence of malaria infection	no data	no data	no data		*Probability of re-infection per week after clearing existing infections with drugs*		
					1996: 0.087[a]	0.109[a]	0.241[b]
Prevalence of parasites	Infants (< 1 year) 30.5% ↓ 2.2%	Infants (< 1 year) 47.0% → 3.0%	Children aged 6–40 months 85.1% ↓ 37.1%	 78.0% ↓ 78.6%	Children aged 1–5 years 1995: 95.7%[a] ↓ 1996: 66.8%[a] ↓ 1999: 38.7%[a]	 88.4%[a] ↓ 68.3%[a]	 94.2%[a] ↓ 74.6%[b] ↓ 83.1%[b]
		1–4 years 54.5% → 5.4%					
Anaemia or malaria in outpatients	*Mean haemo-globin (g/dl)* *at <2 years*: 8.9 → 11.1 at 2–9 years: 10.8 → 12.5	Malaria positivity reduced among out-patients	*% packed cell volume <33%* 76.0% ↓ 23.9%	 78.0% ↓ 50.5%	*Mean haemoglobin (g/dl) at 1–5 years* 1995: 9.25[a] ↓ 1996: 10.13[a] ↓ 1999: 9.91[a]	 9.04[b] ↓ 10.03[a]	 8.69[b] ↓ 9.31[b] ↓ 9.18[b]
Mortality rate/1000	Infants 210 → 105 1–4 years 26 → 12.5	no data	no data		no data		

[a] Data from the same trial and in the same row that did not differ statistically significantly (P>0.05) share the same superscript letters.

The incidence of re-infection with malaria was measured at four different seasons following clearance of existing infections with chlorproguanil–dapsone treatment. After a small correction of the data for the few recrudescences that occur after use of this drug (*11*), it was concluded that both spraying and netting interventions reduced incidence by about 60%, substantially less than might have been expected from the entomological data. This discrepancy has been observed previously (*11*).

In the Muheza trials there were small but significant reductions in parasite prevalence in the year after the interventions were introduced (1996). There was also a reduction in parasite prevalence in control villages, presumably because the project supplied drugs to village health workers and treated children found to be positive by surveys. But the reduction was not as large as that in the intervention villages. Follow-up data in 1999 from the netted (but not the sprayed) villages 3–4 years after providing the nets (with annual re-treatment) showed that the insecticide-treated nets reduced parasite prevalence significantly, compared with a new set of control villages.

In the Muheza trial haemoglobin concentration in treated populations was significantly higher than that in control populations in 1996 a year after the interventions were introduced. Interpretation of the data was complicated, however, by significant pre-intervention differences in villages which later received nets, and by some improvement in haemoglobin levels during the year in the control villages. The insecticide-treated nets continued to

Table 2. **Effects of insecticide-treated materials and house spraying in Kenya and West Africa**

	Location and dates of study							
	Lowland areas of Kenya				Sudan savannah of West Africa			
	1. Kisumu 1972–76 (*13, 14*)		2. Kilifi 1991–95 (*15–17*)		3. Garki, Nigeria 1971–73 (*18*)		4. Ouagadougou, Burkina Faso 1993–95 (*20–22*)	
Treatment/ control areas	Fenitrothion spray	Control area	Permethrin-treated nets	Control area	Propoxur spray	Control area	Permethrin-treated curtains	Control area
Impact on vector populations	Human biting catch/night *An. funestus*		Human biting catch/night indoors, outside nets		Human biting catch of *An. gambiae s.l.*		Infective bites per person per year	
	6.4 → 0[a]	6.2 → no data	95.4 → 23.5	5.3 → 3.7	324.0 ↓ 38.6	73.6 ↓ 64.5	5.4	300
	An. gambiae s.l.		Human-fed mosquitoes found resting per room					
	8.4 → 0.23	10 → 53	0.048	1.12				
	Sporozoite rate		Sporozoite rate		Sporozoite rate		Sporozoite rate	
	6.6% → 1/1010	4.3% → 4.2%	4.9%	5.0%	1.4% ↓ 0.8%	1.7% ↓ 1.8%	4.2%	11.5%
Incidence of infection	Infant parasite conversion/week		Infant parasite and serological conversion rates/week		Infant parasite conversion rate/week		no data	
	0.065							
	↓ 0.0026	↓ 0.061	0.0138	0.026	0.081 ↓ 0.014	0.107 ↓ 0.048		
Parasite prevalence (%)	All ages		Infants (< 1 year)		Age < 1 year		Age < 2 years	
	49 ↓ 17	58 ↓ 58	11.9	25.1	65 ↓ 10	65 ↓ 49	75	88
					Age 1–4 years		Age 2–6 years	
					93 → 49	91 → 82	85	91
Malaria fever	no data		No. of cases with severe malaria in hospital per 1000 population		Temperature>37.4°C in those < 9 years		Fever with >1000 parasites/μl	
			15.0 → 11.0	18.5 → 20.0	3.8%	11.1%	12%	11%
			Protective efficacy = 44% (95% confidence interval 19–62%)					
Mortality rate per 1000	Infants (< 1 year) (deaths per 1000 live births)		Age 1 month–5 years		Age 1–4 years		Age 1 month–5 years	
	93	157	15.8 → 9.4[a]	14.9 → 13.2[b]	111 ↓ 83	159 ↓ 114	41.8[a]	48.7[a]
	All age groups		Protective efficacy = 30% (95% confidence interval 7–47%)				Protective efficacy = 14% (95% confidence interval –4 to 30%)	
	23.9 → 13.5	23.3 → 24.4						

[a] Arrows (vertical or horizontal) link pre-intervention data with data from the same areas during the intervention. Data from the same trial and in the same row that did not differ statistically significantly share the same superscript letter.

improve haemoglobin levels in 1999, 3–4 years after introduction, but the improvement in haemoglobin level appeared to be less than the increase of about 1.9 g Hb/dl reported in the Pare-Taveta scheme (Table 1, compare columns 1 and 4).

In summary, the Muheza trial showed that after one year there were no significant differences between using lambdacyhalothrin for net treatment or for house spraying for all outcomes assessed (Table 1, column 4). Similarly, after one year the results at Bagamoyo and Muheza (Table 1, columns 3 and 4) were not as good as those seen in the spraying projects in the 1950s and 1960s which ran for several years (Table 1, columns 1 and 2). Continuing observations

Table 3. **Comparison of treatment efficacies in areas outside tropical Africa**

Location	Treatment	Impacts			
1. KwaZulu Natal, South Africa (*24*)		*Cases per 1000 person years*			
		1996	*1997*	*1998*	*1999*
	Deltamethrin-treated nets	228	188	191	158[a]
	Deltamethrin spray	189	201	274	222[b]
2. Hubei, China (*28*)		*No. of An. anthropophagus resting indoors*		*% of blood films positive for malaria among fever cases*	
	Deltamethrin-treated nets	6		2.8[a]	
	DDT spray	9		3.0[a]	
	Control	180		7.5[b]	
3. North West Frontier Province, Pakistan (*29–31*)		*Cases of*		*Protective efficacy (%)*	
	Malathion spray	*P. falciparum*		52.5	
		P. vivax		40.5	
	Permethrin-treated nets	*P. falciparum*		61	
		P. vivax		47	
4. Gujarat, India (*33*)				*Cases of parasite positivity in those complaining of fever per 1000 person years*	
	Deltamethrin-treated nets	Mosquito parity lower in villages with nets, but density in untreated rooms not significantly different in treated and control villages		28.1[a]	
	Deltamethrin spray			43.6[b]	
	Control			61.5[c]	
5. Solomon Islands (*35*)		*An. punctulatus* almost eliminated		*An. farauti* human biting	*An. farauti* exit trap mortality (%)
	Permethrin-treated nets			3.90	98.2
	DDT spray			9.38	10.1
	Control			8.47	11.6

[a] Data from the same trial and in the same column that do not differ statistically significantly share the same superscript letter.

on insecticide-treated nets at Muheza showed more convincing benefits, in contrast to fears that benefits would fade with time because of loss of immunity. The results suggest that the recent tendency to rely on 1–2 year trials is insufficient for the parasite reservoir to be drained, and for the full benefits of sustained vector control to be seen. Nevertheless, after 3–4 years in the Muheza villages, the impacts on parasite prevalence and haemoglobin levels did not seem to be as good as in the old spraying trials.

Table 2 (columns 1 and 2) shows data from lowland areas of Kenya from a WHO-sponsored trial of spraying with fenitrothion near Kisumu in the 1970s (*13, 14*), and a WHO-sponsored insecticide-treated net trial near Kilifi in the 1990s (*15–17*). The spraying reduced *An. funestus* to undetectable levels, and the same was true for *An. gambiae* in the dry seasons. But in a season of very heavy rain (to which the entomological data in Table 2, column 1 refer), a small number of *An. gambiae* reappeared in the sprayed area (with a single sporozoite positive individual among over 1000 examined). Meanwhile there was an upsurge of this species in the rainy season in the control area. In the insecticide-treated net trial there was a major reduction in anophelines resting in rooms with the insecticide-treated nets, but no evidence for any reduction in the sporozoite rate, in contrast with the results at Muheza, United Republic of Tanzania (Table 1, column 4).

Both of the trials in Kenya assessed the incidence of infection, using the conversion rate of infants to parasite positivity for the first time in their lives (in the case of the insecticide-treated net trial, conversion to antibody positivity was also taken into account). The spraying caused a more than 20-fold reduction in incidence compared with pre-intervention or contemporary control data, but the insecticide-treated nets reduced incidence to only about one-half that in the control areas. Parasite prevalence was more markedly reduced in all age groups by the spraying trial, than in infants by the insecticide-treated nets. Using an equation of Macdonald and earlier data on the natural rate of recovery from *P. falciparum* infections, it was calculated that, had the spraying at Kisumu continued, an eventual reduction of the parasite prevalence to 6.5% would have been expected (*13*).

The insecticide-treated net trial at Kilifi has so far been the only one where the incidence of severe malaria cases in hospital has been assessed, and this was significantly reduced (best estimate of 44% for protective efficacy (i.e. 1-the ratio of the incidence rates)). The main purpose of the Kilifi insecticide-treated net trial was to determine the effect on all-cause child mortality. A significant reduction (best estimate 30%) was detected (Table 2, column 2). This was less than the best estimate of 43.5% reduction recorded for all age groups in the Kisumu spraying trial, though the upper 95% confidence limits of the estimate from the insecticide-treated net trial overlaps with the best estimate from the spraying trial (Table 2, columns 1 and 2). In all respects the spraying appeared to be more efficacious than the insecticide-treated nets. It is possible that this was at least partly due to differences in the ecology of the sites and composition of the vector populations. A large-scale insecticide-treated net project has recently been conducted near Kisumu. When the results are published it will be interesting to compare them with those of the two trials just discussed.

Sudan savannah zone of West Africa

In the 1970s an influential trial of house spraying, using propoxur, was conducted at Garki, northern Nigeria, and the results were analyzed in detail (*18*). The trial included mass drug administration in some of the villages, but this will not be considered here. As shown in Table 2 column 3, the spraying caused major reductions in the total population of vectors and the overall sporozoite rate. There were also clear reductions in malaria incidence in infants, parasite prevalence and fever, and an apparent effect on mortality in the 1–4 year age group. However, the malaria results fell well short of the interruption of transmission that the authors were hoping for. The authors concluded that, against vector populations prevalent in the Sudan savannah zone, satisfactory vector control could not be achieved by house spraying, even with an insecticide to which the vectors were fully susceptible and with virtually 100% coverage. They pointed out that results were not as good as in the contemporaneous trial at Kisumu (Table 2, column 1) and that, in contrast to the effects in Kisumu, continuation of the spraying in Garki would not have further reduced the parasite prevalence, which had already reached a new equilibrium between incidence and recovery. The authors suggested that the problem in the Sudan savannah zone was the genetic complexity of the *An. arabiensis* and *An. gambiae s.s.* vector populations, within which there were inversion types that tended to be consistently exophilic and therefore invulnerable to house spraying (*19*). They suggested that, though the overall anopheline population was much reduced, there was a minority concealed within this population that was untouched and was numerous enough to keep transmission going at an unacceptably high level.

One of the WHO-organized trials on the impact of insecticide-treated materials was in Burkina Faso, using permethrin-treated curtains (*20–22*). Table 2 column 4 shows that the widespread use of curtains had a marked "mass effect" on the numbers and sporozoite rate of the vector population. However, the impact on prevalence of parasites and fever were slight or non-existent. Child mortality was the major outcome variable and, though there was an apparent effect on this, the difference between treated and control areas was not statistically significant. Observations on mortality have continued in the Burkina Faso trial and, when the results are published, they will be of great interest. This trial was in approximately the same ecological zone as Garki. The results so far published do not indicate that the apparent problem at Garki, that of a partially exophilic vector population, is solved by intercepting host-seeking mosquitoes as they try to enter huts. Even so, this intervention would still not impact transmission by wholly exophagic mosquitoes.

Outside tropical Africa

Table 3 summarizes data from side-by-side comparative trials of spraying and insecticide-treated nets outside tropical Africa. In the malarious parts of KwaZulu Natal, South Africa, DDT spraying was carried out for 50 years up to 1994. A comparison of survival of *An. arabiensis* exiting from houses sprayed with DDT or with a pyrethroid showed better killing with the latter (*23*). From 1995, there was a switch to spraying with the pyrethroid, deltamethrin, in most of the area, with a trial of pyrethroid-treated nets in part of the area (in 1997, with both treatments in the same houses, but latterly with only nets treated with deltamethrin) (*24*). As shown in Table 3, row 1, the pyrethroid spraying failed to prevent a rise in malaria cases. This has been attributed to *An. funestus*, which apparently had been eradicated by DDT in the 1950s, but has re-emerged and now shows pyrethroid resistance (*25*). This resistance is not of the *kdr* type, which causes cross resistance to DDT, and has recently been found in three West African countries (*26*). It appears that, against the resistant vectors found in KwaZulu Natal, the physical barrier provided by a net plus the excito-repellent effect of permethrin is a more effective method than house spraying with a pyrethroid. It is interesting to note that permethrin- or deltamethrin-treated nets also showed continued effectiveness against a West African *An. gambiae s.s* population with resistance of the *kdr* type (*27*).

In areas of Hubei province, China, where *An. anthropophagus* is the vector of *P. vivax*, DDT spraying was compared with deltamethrin treatment of nets, which almost everyone owns (*28*). Compared with the untreated comparison area, both the numbers of vectors resting indoors and the number of fever cases, diagnosed by the primary health care system as being *P. vivax* positive, were reduced equally by the two vector control methods (Table 3, row 2).

In the villages of mud houses inhabited by displaced populations along the Afghan–Pakistan frontier, a variety of vector control methods were tested against the dual problems of *P. falciparum* and *P. vivax* malaria (Table 3, row 3; *29–31*). With permethrin-treated nets, although the number of malaria cases was slightly lower than that observed after spraying houses with malathion, the difference was not significant. One of the two vector species, *An. stephensi*, is known to be resistant to malathion in the area, and switching from malathion to lambda-cyhalothrin for house spraying raised the protective efficacy to almost exactly the same level as with treated nets. Thus, as in the Muheza comparison (Table 1, column 4), a pyrethroid used either for net treatment or for house spraying gave indistinguishable results. It should also be noted that the protective efficacy in the Pakistani trials of about 50% is very modest, when compared with the near eradication of malaria achieved over much of the Indian subcontinent by sustained campaigns of DDT house spraying in the 1950s–60s (*32*). However, a sustained campaign of malathion spraying, plus 30% coverage with insecticide-treated nets, reduced the incidence of malaria cases by 90% in the Pakistani trials (*30*). With both methods, the impact on *P. falciparum* was greater than on *P. vivax*, no doubt because some of the *P. vivax* cases were relapses of existing infections, and thus not susceptible to short-term vector control.

In 126 villages in Gujarat state in north-west India, a comparative trial with deltamethrin, used either for net treatment or for house spraying, was carried out against malaria transmitted by *An. culicifacies* species A (*33*; Table 3, row 4). There was no significant reduction in village vector populations due to either treatment, measured by pyrethrum spray catches of mosquitoes resting in untreated rooms. However, the parity rate (a measure of mosquito survival) was significantly less in the villages that used nets. This would lead one to expect a markedly lower rate of infective biting in those villages. Indeed, the incidence of malaria cases, determined by inspectors taking blood films from those complaining of fever, was significantly less in villages with insecticide-treated nets than in sprayed villages, and both showed significantly lower incidences than in control villages.

In the Solomon Islands, a long-term DDT spraying programme had ceased to be effective (*34*), partly because one of the vector species, *An. farauti*, had evolved behavioural resistance (outdoor biting early in the evening). A trial with permethrin-treated nets showed apparent eradication of the vector species *An. punctulatus* (*35*) (Table 3, row 5). A comparison with DDT spraying in experimental huts showed a high rate of delayed mortality in *An. farauti* caught exiting from a hut with an insecticide-treated net, but in the DDT sprayed hut delayed morbidity was no higher than in the untreated control. The results suggest that the mosquitoes were not physiologically resistant to DDT. Instead, they were avoiding lethal contact with DDT, but not with the permethrin deposit on the net. On each of several of the Solomon Islands, comparisons of insecticide-treated nets with DDT spraying suggested that malaria was controlled better by insecticide-treated nets (*36*).

Discussion

Conclusions regarding the efficacy of insecticide-treated nets and house spraying

The six recent side-by-side comparisons of insecticide-treated nets treated with a pyrethroid, and house spraying with pyrethroids, DDT or malathion, all showed that insecticide-treated nets were at least as efficacious as spraying (Table 1, column 4; Table 3). However, when recent outcomes from insecticide-treated nets and spraying are compared with spraying projects from the 1950s–70s, against apparently similar vector populations, the recent results appear to be inferior (Tables 1 and 2). We are uncertain how to explain this paradox. Some current spraying operations suffer from poor coverage rates, because of low staff morale and lack of public understanding and support; and some insecticide-treated net operations have seen coverage rates decline greatly when they switched to a system of demanding payment for net re-treatment (*37*). However, most of the insecticide-treated net trials described here involved free distribution of nets and re-treatment by research teams and we think it unlikely that the coverage and re-treatment rates were markedly worse than in the old spraying projects. In many of the old projects chloroquine was more effective, since the parasite populations were fully susceptible, unlike the situation in most places today. However, in those of the projects described here where there was a control, unsprayed, area this would also have benefited equally from very effective chloroquine treatment, but major differences between sprayed and control areas were nevertheless seen (Table 2).

A more relevant factor is probably that most of the insecticide-treated net trials have not continued, or been reported, for a long enough duration to show their full potential. In the recent trials demonstration of a statistically significant benefit has been considered a "success" but during and in the aftermath of the malaria eradications of the 1940s–60s, anything less than the local elimination of malaria would have been considered a "failure". However, the longer continuation times of the older projects does not fully explain the discrepancies, and we are beginning to question the modern view that pyrethroids are the best class of insecticide. Their excito-repellent properties, which are thought to be an important part of their action on nets, may have the effect of driving some mosquitoes away without killing them. We note that two of the most successful projects, those at Pare-Taveta (Table 1, column 1) and at Kisumu (Table 2, column 1), both used relatively non-irritant insecticides. DDT is also an irritant, but in Zanzibar (Table 1, column 2) its use nearly eradicated a previously holoendemic malaria problem. However, this 10-year project was the most prolonged of all those shown in the tables. Malathion, another relatively non-irritant insecticide, did not perform particularly well compared with insecticide-treated nets in Pakistan (Table 3, row 3) but, as already noted, one of the local vector species was resistant to it.

Before the remarkable successes of the past are forgotten and the view takes hold that all that can be hoped for from vector control is merely a significant amelioration of malaria problems, we would like to see side-by-side comparisons of pyrethroids with powerful, but relatively low-irritant insecticides. One suggestion is an attempted re-run of the remarkable success of fenitrothion spraying in the Kisumu project. Another is a village scale follow-up to a successful hut trial of carbosulfan on nets (*38*). This carbamate has a similar mammalian toxicity to the commonly used pyrethroids (*39*) and in the hut trial gave close to 100% mortality of an *An. gambiae* population carrying the *kdr* resistance gene. This is a higher mortality than has ever been achieved in hut tests with any pyrethroid, even against a susceptible mosquito population (*40*).

Economic and political issues

Even if it is accepted that pyrethroid-treated nets are only modestly effective, compared to spraying, is it the case that insecticide-treated nets are the only form of malaria vector control which is now politically and economically feasible on an extensive scale? Even in the 1970s, the cost of fenitrothion spraying four times a year, which was necessary to achieve the Kisumu results, was US$ 3.24 per head of population (*14*), equivalent to about US$ 7.65 today.

In contrast, the area of a family's net is much less than that of the walls and ceiling of their house (e.g. on average six-fold less in Tanzanian villages) (*9*). Thus, net treatment requires less insecticide per family protected than house spraying, and this economy can more than counterbalance the cost of bulk-purchased nets with several years of useful life. Calculations based on net replacement every four years and annual re-treatment with a rather expensive formulation of lambdacyhalothrin, indicated that a spraying programme in the United Republic of Tanzania would be about twice as expensive as an insecticide-treated net programme (about US$ 1 per head for insecticide-treated nets compared with over US$ 2 for spraying; *9*). However, in South Africa (*41*) and in Pakistan (*29*), it was calculated that spraying programmes would be cheaper than using insecticide-treated nets. In the People's Republic of China (*42*) and the Solomon Islands (*43*) it was calculated that it would be cheaper for village health workers to treat existing nets with bulk-packaged pyrethroids, than DDT spraying by professional spray teams, for the same number of houses. However, this might not be true if expensively packaged "dip-it-yourself" sachets of insecticide have to be bought (*44, 45*).

In epidemic-prone areas one can envisage a "fire-brigade" approach with a trained spray team equipped with spray pumps and insecticide, ready to go as soon as prediction indicators warn of an imminent epidemic. The very serious epidemic in the highlands of Madagascar in the late 1980s was brought under control by the resumption of DDT spraying (*46*), although the three year delay, from the beginning of the epidemic to the beginning of spraying, could hardly be compared to the performance of a fire brigade. It seems more feasible to maintain a capacity to react by spraying, than to maintain large stocks of nets for issue in the event of an epidemic.

Malaria vector control is a major consideration when organizing health care provision for displaced populations, especially where individuals lack malaria immunity, but are encamped in highly endemic areas. In deciding between nets and spraying, two problems to consider are that shelters for displaced populations may be too small to accommodate nets, and that shelters made from plastic sheeting may be unsuitable for spraying because the insecticide deposit cannot adhere to smooth plastic surfaces (*29–31*). In the western region of the United Republic of Tanzania, about a half-million displaced people from the Democratic Republic of the Congo, Rwanda and Burundi were recently issued with lambdacyhalothrin-treated nets, and shelters in some of the camps were also sprayed with the same insecticide (*47*). A survey showed that either or both of these interventions had a beneficial effect on malaria parameters. However, one year later, 19% of the nets were missing, half having been sold, and 35% needed to be replaced. These problems were less severe in longer-established camps and even less serious in stable Tanzanian villages, where 3–4 years after provision of nets, 85% of children still had them. Even though 35% of them were by then in poor condition, the health benefits to the children in these villages, compared to villages without nets, were not significantly associated with the condition of their nets. This indicates that the benefits were mainly due to the communal effect of many mosquitoes being killed on the insecticide-treated fabric over most of the beds in these villages (Table 1, column 4, 1999 data; Maxwell, Msuya and Curtis, unpublished observations).

A further example of where the use of insecticide-treated nets is expected to have a communal benefit is in the remaining malarious northern parts of KwaZulu-Natal, South Africa, where effective malaria control not only benefits the local population, but is also intended to prevent malaria spreading back into the much larger populations further south where malaria has been eradicated (*48*). In these circumstances it is considered inappropriate to try to make individual users pay for nets and insecticide.

It is widely considered that the extensive use of bednets and insecticide will only be possible if they are sold to householders, rather than provided free as a part of the public health service, as house spraying was or is. However, in our opinion it would be deplorable if a switch from house spraying to insecticide-treated nets was, in effect, a means of removing the responsibility for payment for malaria control from affluent taxpayers in endemic and/or donor countries, and placing it on to the narrow shoulders of subsistence farmers, whose poverty arises partly from their affliction with malaria. Where it has been decided that nets and insecticide must be paid for by their users, it has been found that an elaborate infrastructure has to be set up if high net re-treatment rates are to be achieved (e.g. *45*). On the other hand, we have found in South Africa and the United Republic of Tanzania that an annual, pre-arranged, one or two day visit to each village by an experienced supervisor, who provides free insecticide to village health workers, achieves high re-treatment rates which have led to sustained reductions in the incidence of malaria cases, or in the chronic effects of malaria infections.

Conclusion

In projects with free, organized provision of insecticide-treated nets and pyrethroids for re-impregnation high population coverage can be achieved, apparently comparable to that in the best house spraying projects of 25–40 years ago. The impact on malaria reported with insecticide-treated nets seems good compared with recent spraying trials, but we have to admit that it has not matched up to that of the older spraying projects. It may be possible to improve on insecticide-treated net results by carrying on monitoring for several years and by using less irritant classes of insecticide. ■

Acknowledgements

We are grateful to Brian Sharp, Jo Lines, Simon Cousens and Mark Rowland for comments on the manuscript.

Résumé

Lutte antipaludique : comparaison entre les pulvérisations domiciliaires et l'utilisation de moustiquaires imprégnées d'insecticide

L'article examine les données résultant d'essais récents effectués dans six pays en vue de comparer l'efficacité contre les vecteurs du paludisme des pulvérisations à effet rémanent dans les habitations et celle de l'utilisation de moustiquaires imprégnées de pyréthrinoïdes. En République-Unie de Tanzanie, le lambdacyhalothrine en pulvérisations domiciliaires et utilisé pour l'imprégnation des moustiquaires avait des effets comparables sur les paramètres suivants : densité vectorielle ; indice sporozoïtique ; activité trophique dans les pièces traitées ; incidence de la réinfestation après élimination du parasite et taux d'hémoglobine chez les enfants. En Afrique du Sud, les pulvérisations de deltaméthrine n'ont pas permis de prévenir l'augmentation du nombre des cas de paludisme observée depuis 1997, due apparemment à l'émergence d'*Anopheles funestus* résistant aux pyréthrinoïdes, mais l'utilisation de moustiquaires imprégnées de pyréthrinoïdes a provoqué un léger recul du nombre des cas. En République populaire de Chine, les pulvérisations de dichlorodiphényltrichloroéthane (DDT) et l'utilisation de moustiquaires imprégnées de deltaméthrine ont eu des effets comparables sur le nombre des cas de paludisme. Des résultats analogues ont également été observés dans les populations afghanes déplacées au Pakistan avec le traitement des habitations au malathion et l'utilisation de moustiquaires imprégnées de perméthrine. En Inde, les cas de paludisme dépistés ont été moins nombreux après l'utilisation de moustiquaires imprégnées de deltaméthrine qu'après les pulvérisations domiciliaires de deltaméthrine. Dans les Iles Salomon, où *A. farauti* est devenu résistant au traitement des habitations en adaptant son comportement, l'utilisation de moustiquaires imprégnées de perméthrine, contrairement aux pulvérisations de DDT, a été assortie d'une forte mortalité des moustiques sortant des habitations traitées.

Le tableau est différent lorsqu'on compare des essais récents effectués avec des moustiquaires ou des rideaux imprégnés en République-Unie de Tanzanie, au Kenya et au Burkina Faso à des projets utilisant le traitement des habitations contre des populations de vecteurs apparemment comparables, réalisés entre les années 50 et 70. Les pulvérisations domiciliaires de dieldrine dans le cadre du projet mis en œuvre dans les années 50 dans la zone de Pare-Taveta en République-Unie de Tanzanie et au Kenya ont permis de réduire de moitié la mortalité toutes causes confondues, ce qui est supérieur aux résultats des essais récents organisés par l'OMS avec des étoffes imprégnées de pyréthrinoïdes. Le projet de pulvérisations a également entraîné une amélioration des taux d'hémoglobine des enfants plus sensible que l'amélioration observée récemment après l'utilisation de moustiquaires imprégnées en République-Unie de Tanzanie. A Zanzibar dans les années 60, un niveau de paludisme précédemment holoendémique a été ramené à un indice plasmodique de 3-5 % chez les enfants par 10 années de traitement des habitations au DDT – soit une réduction nettement supérieure aux résultats obtenus pour tous les autres projets utilisant des moustiquaires imprégnées. Dans les années 70, les pulvérisations de fénitrothion près de Kisumu au Kenya ont eu pour effet de réduire de 20 fois environ le taux de nourrissons positifs pour la première fois tandis que, dans les années 90, les moustiquaires imprégnées à Kilifi au Kenya n'ont permis de réduire les taux que de moitié. La mortalité semblait aussi avoir été réduite sensiblement dans l'essai de Kisumu.

Les auteurs d'un essai de pulvérisations de propoxur réalisé à Garki au Nigéria dans les années 70 ont considéré que les résultats obtenus témoignaient de l'impossibilité de combattre efficacement le paludisme

par le traitement des habitations dans la zone de savane du Soudan, où une partie de la population de *A. gambiae s.l.* est régulièrement exophile. Les résultats dont il est fait état à ce jour concernant les tentures imprégnées de perméthrine, dans une zone identique du Burkina Faso, n'étaient cependant pas meilleurs que ceux de Garki, et même plus mauvais à certains égards.

Paradoxalement, on constate donc que si les comparaisons récentes pulvérisations-moustiquaires imprégnées ont toutes penché en faveur des moustiquaires imprégnées, celles-ci ne soutiennent pas avantageusement la comparaison avec des projets de pulvérisations antérieurs. Une explication possible, qui mériterait plus ample examen, est que les insecticides relativement peu irritants, comme ceux qui sont utilisés dans plusieurs projets de pulvérisations, tuent plus de moustiques que les pyréthrinoïdes, qui ont un effet répulsif sur les moustiques mais ne les tuent pas.

La plupart des comparaisons entre le coût des pulvérisations et celui des moustiquaires imprégnées sont favorables à ces dernières. On estime couramment que les personnes exposées au risque de paludisme devront assumer le coût de l'imprégnation des moustiquaires. Il serait regrettable qu'un changement de politique, à savoir l'adoption des moustiquaires imprégnées aux dépens du traitement des habitations, ait pour effet de faire peser la responsabilité financière de la lutte antipaludique non plus sur les contribuables nantis mais sur les paysans pratiquant une agriculture de subsistance. Cette étude montre que la réimprégnation des moustiquaires peut être organisée facilement et à moindres frais au niveau communautaire, et qu'elle permet une couverture importante de la population. Toutefois, les bienfaits observés à ce jour restent modestes par rapport aux résultats des pulvérisations domiciliaires effectuées il y a 25-40 ans.

Resumen

Comparación del rociamiento de hogares y de los mosquiteros tratados con insecticida en la lucha contra el paludismo

Se examinan los datos aportados por ensayos llevados a cabo recientemente en seis países para comparar la eficacia del rociamiento de acción residual de los hogares con la de los mosquiteros impregnados de piretroide como formas de lucha contra los vectores del paludismo. En la República Unida de Tanzanía, la lambda-cihalotrina utilizada ya fuera para rociar o para impregnar los mosquiteros tuvo efectos similares en lo siguiente: la densidad del vector; la tasa de esporozoítos; la intensidad de la hematofagia en las habitaciones tratadas; la incidencia de reinfecciones; y los niveles de hemoglobina en los niños. En Sudáfrica, el rociamiento con deltametrina no impidió que a partir de 1997 se produjera un aumento del número de casos de paludismo, causado al parecer por la aparición de *Anopheles Funestus* resistente a los piretroides, pero se observó una ligera disminución del número de casos cuando se emplearon mosquiteros tratados con piretroides. En la República Popular China, el rociamiento con diclorodifeniltricloroetano (DDT) y los mosquiteros tratados con deltametrina influyeron de forma similar en el número de casos de paludismo. El rociamiento con malatión y el empleo de mosquiteros tratados con permetrina también se tradujeron en resultados similares en poblaciones desplazadas afganas en el Pakistán. En la India, el número de casos de paludismo detectados cuando se utilizó deltametrina para tratar los mosquiteros fue menor que cuando se hicieron rociamientos con ese producto. En las Islas Salomón, donde *A. farauti* se ha hecho resistente al rociamiento de hogares adaptando su comportamiento, los mosquiteros tratados con permetrina causaron una alta mortalidad entre los mosquitos que abandonaban las casas tratadas, mientras que el rociamiento con DDT no tuvo ese efecto.

El panorama cambia cuando los ensayos llevados a cabo recientemente con mosquiteros o cortinas tratados en la República Unida de Tanzanía, Kenya y Burkina Faso se comparan con los proyectos emprendidos entre los años cincuenta y setenta mediante el rociamiento de hogares contra poblaciones de vectores aparentemente comparables. El proyecto llevado a cabo en los años cincuenta en la zona de Pare-Taveta de la República Unida de Tanzanía y Kenya, en el que se recurrió al rociamiento con dieldrina, redujo a la mitad la mortalidad por todas las causas, lo cual supera los resultados obtenidos en los recientes ensayos organizados por la OMS con material impregnado de piretroides. El proyecto de rociamiento mejoró asimismo la hemoglobinemia de los niños, que superó los niveles observados recientemente con los mosquiteros tratados en la República Unida de Tanzanía. En Zanzíbar, en los años sesenta, los casos de paludismo, hasta entonces holoendémico, se redujeron hasta alcanzarse una prevalencia del parásito del 3%-5% en los niños al cabo de 10 años de rociamiento de los hogares con DDT, lo que supone una reducción mucho mayor que la notificada por cualquiera de los proyectos emprendidos con mosquiteros tratados. En los años setenta el rociamiento con fenitrotión cerca de Kisumu (Kenya) redujo unas 20 veces la tasa de conversión positiva para el parásito entre los lactantes, mientras que en los años noventa los mosquiteros tratados de Kilifi (Kenya) sólo redujeron las tasas a la mitad. También la mortalidad se redujo de forma más pronunciada en el ensayo de Kisumu.

Se ha considerado que los resultados de un ensayo de rociamiento con propoxur llevado a cabo en Garki (Nigeria) en los años setenta demostraron que el rociamiento de hogares no combate de forma satisfactoria el paludismo en la sabana sudanesa en África, donde una proporción de la población de *A. gambiae s.l.* es sistemáticamente exófila. Sin embargo, los resultados notificados hasta ahora respecto a las cortinas tratadas con permetrina, en la misma zona de Burkina Faso, no son mejores que los de Garki, y en algunos aspectos son incluso peores.

Se da pues la paradoja de que, mientras que las recientes comparaciones paralelas del rociamiento y los mosquiteros tratados han sido en todos los casos favorables a estos últimos, los mosquiteros tratados no dan mejores resultados que los antiguos proyectos de rociamiento. Una posible explicación, que merece ser investigada, es que los insecticidas con efectos irritadores relativamente leves, como son los usados en varios de los proyectos de rociamiento, matan más mosquitos que los piretroides, que pueden alejar a los insectos sin matarlos.

En lo referente al costo, la mayoría de las comparaciones entre el rociamiento y los mosquiteros tratados son favorables a estos últimos. Muchos consideran que las personas en riesgo de paludismo tendrán que pagar por el tratamiento de sus mosquiteros. Sería lamentable que como consecuencia de un cambio de política -fomento de los mosquiteros tratados por oposición al rociamiento de hogares- la lucha antipalúdica acabase siendo costeada no por los contribuyentes prósperos, sino por agricultores que viven con ingresos de subsistencia. Esta revisión muestra que el tratamiento repetido gratuito y comunitario de los mosquiteros es una opción barata y fácilmente viable y hace posible una alta cobertura de la población. Sin embargo, las mejoras logradas hasta ahora han sido relativamente discretas en comparación con las conseguidas mediante el rociamiento de los hogares hace 25-40 años.

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