Journal of the American Mosquito Control Association, 20(4):424–428, 2004

FOLLOW-UP STUDIES AFTER WITHDRAWAL OF DELTAMETHRIN SPRAYING AGAINST *ANOPHELES CULICIFACIES* AND MALARIA INCIDENCE

MUSHARRAF ALI ANSARI AND RAMA KRISHNA RAZDAN

Malaria Research Centre (ICMR), 20-Madhuban, Delhi-110 092, India

ABSTRACT. Follow-up studies were carried out from 1989 to 1998 after withdrawal of deltamethrin indoor spraying to evaluate the recovery rate of a population of *Anopheles culicifacies* resistant to dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane (HCH) in selected villages in Uttar Pradesh State, India. The study revealed 82.4–96.5% reduction in adult density of *An. culicifacies* and 72.7–96% reduction in malaria incidence in the area sprayed with deltamethrin at 20 mg/m^2 as compared to a control area sprayed with HCH, for 5 successive years even after withdrawal of deltamethrin spray. The impact was very clear when the annual falciparum incidence was compared with that of the control area. The vector population gradually started recovering after 5 years. However, the slide falciparum rate remained below 4 even after 10 years of withdrawal of spraying. The study revealed that indoor residual spraying of deltamethrin would be cost-effective, at least in areas where malaria is transmitted by *An. culicifacies,* which is primarily a zoophilic species and associated with malaria epidemics. In view of this, a review of the insecticide policy and strategy of vector control is urgently needed because of the possible risks associated with the presence of nonbiodegradable insecticide in the environment, as well as to minimize the costs of operation and to enhance the useful life of insecticides.

KEY WORDS *Anopheles culicifacies,* deltamethrin, vector control, impact of residual spraying

INTRODUCTION

Anopheles culicifacies Giles (Diptera: Culicidae) is a principal vector of malaria and is responsible for 70–75% of malaria transmission in the northern plains of India. Resistance to dichlorodiphenyltrichloroethane (DDT), hexachlorocyclohexane (HCH), and malathion is detectable in Maharashtra, Gujarat, and Haryana states (Pillai 1996). A field trial was carried out in Razapur Primary Health Centre (PHC), Ghaziabad District (Uttar Pradesh), during 1986–88 to evaluate the efficacy of deltamethrin applied at 12.5, 20, and 25 mg/m^2 against DDT- and HCH-resistant *An. culicifacies* and the impact of spraying on malaria incidence. Results revealed drastic reduction in the vector population and malaria incidence in the sprayed villages (Ansari et al. 1990). Because the cost of the synthetic pyrethroid was much higher than that of the commonly used insecticides DDT and HCH, follow-up studies were carried out after the 3 years of deltamethrin spraying to assess the cost–benefit ratio of synthetic pyrethriods in comparison to convential insecticides which are generally used every year without effectively suppressing the vector population or incidence of malaria. Results of follow-up studies carried out from 1989 to 1998 after withdrawal of insecticide pressure are presented in this paper.

MATERIALS AND METHODS

The study was carried out from 1989 to 1998 in Razapur PHC, which is situated in Ghaziabad District about 35 km from Delhi. The population of the PHC is about 140,000 distributed in 46 villages in an area of 185 km^2. There are about 18,000 human dwellings and most of the inhabitants are engaged in agriculture. Major crops of this area are wheat, rice, maize, and pulses. The area of the Dadri PHC is about 227 km^2 and the population is about 144,000 distributed in 65 villages. Both experimental and control PHCs are situated on the bank of the upper Ganga canal and the area is irrigated through irrigation channels supplemented by tubewells. The ratio of humans to cattle is 4:1 in Razapur PHC and 7:1 in Dadri PHC. The control PHC was sprayed with HCH at 200 mg/m^2 in 1989 and later the PHC was not sprayed. The Razapur PHC was initially divided into 3 zones. Zone I was sprayed with 3 rounds of deltamethrin at 12.5 mg/m^2 at an interval of 6 wk with stirrup pumps by the trained spray team as per World Health Organization (WHO) guidelines, whereas in only 2 rounds were sprayed zone II and zone III at 20 and 25 mg/m^2, respectively, at an interval of 8 wk during 1986, 1987, and 1988. No insecticide has been sprayed in Razapur PHC since 1989. All the structures in the selected villages, including temporary structures and cattle sheds, were sprayed both inside and outside. All necessary precautions were taken during the spraying operation both in control and experimental villages as per WHO guidelines (WHO 1986).

Initially, village-wise data on the annual parasite incidence (API), mosquito prevalence, malaria cases from 1983 to 1985 in both Razapur and Dadri PHCs were collected from the National Malaria Eradication Programme, Goverment of India. Razapur PHC was selected for deltamethrin spraying because of high mosquito density, DDT and HCH resistance in *An. culicifacies,* and high malaria transmission. Five villages from each zone and PHC were selected for the present study, based on

the average API in the 3 years before the spraying operation (1983–85). During the prespray period, the API was comparable between the control and experimental villages (Ansari et al. 1990).

Mosquitoes were collected by hand by using a suction tube and flashlight between 0600 and 0800 h in each village and zone. Collections were made every 2 wk in 16 randomly selected human dwellings in each village. Collected mosquitoes were identified and the data of all villages in each zone were pooled and annual density per structure was calculated. Door-to-door fortnightly active surveillance also was carried out to detect fever cases. Both thick and thin blood smears were collected from the patients with a fever and were examined microscopically under oil immersion with Giemsa stain. Presumptive treatment (600 mg chloroquine) was given to all patients with a fever, and radical treatment was given to all patients with microscopically confirmed malaria (600 mg chloroquine with 45 mg primaquine for *Plasmodium falciparum* and 15 mg primaquine for 5 day for *Plasmodium vivax*). The data of all 5 villages in each zone were pooled separately and slide positivity rate (SPR), API, annual blood examination rate, slide falciparum rate (SFR), and annual falciparum incidence (AFI) were calculated by using standard formulae. Susceptibility tests were also carried out on mosquitoes collected from all the zones by using WHO standard procedures, by exposing fully fed field-collected *An. culicifacies* and *Culex quinquefasciatus* Say (Diptera: Culicidae) for 1 h to papers impregnated with DDT (4%), malathion (5%), and deltamethrin (0.025%) according to WHO standard procedures. Percent reduction was calculated by using the following formula:

$$\% \text{ reduction} = \frac{\text{control} - \text{treated}}{\text{control}} \times 100$$

Data were statistically analyzed by using Student's *t*-tests for significance. Further meteorological data, such as rainfall and temperature, also were collected from the Meterological Department of Ghaziabad District during the study period to check for any adverse fluctuations in meteorological indicators that might affect mosquito breeding and survival, and malaria transmission.

RESULTS

Entomological evaluation

Percent reduction based on control density of experimental and control villages was calculated and is presented in Fig. 1. Spraying of deltamethrin at 12.5 mg/m^2 (zone I), 20 mg/m^2 (zone II), and 25 mg/m^2 (zone III) resulted in drastic reduction in adult densities of *An. culicifacies*. The percent reduction of adult density was from 76.4 to 96.4% in zone I, from 89.6 to 97.9% in zone II, and from 97.1 to 99.4% in zone III in successive years of

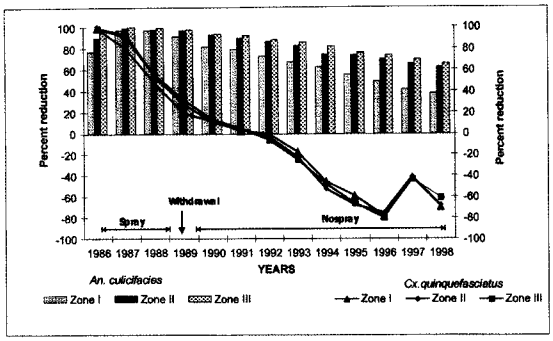

Fig. 1. Percent reduction in mosquito density over the control in experimental villages sprayed with deltamethrin.

spraying (1986–88). This confirms the earlier findings of Ansari et al. (1986), who demonstrated effective malaria control in the village Bhanera of Loni PHC in Ghaziabad District. The impact of earlier spraying was evident for about 5 years, even after withdrawal of the deltamethrin spraying. During 1989–93, the percent reduction ranged from 67.0 to 90.8% in zone I, 82.4 to 96.5% in zone II, and 85.8 to 97.7% in zone III. The entomological impact gradually started diluting from 1994 onward and the degree of dilution was directly proportional to the dosages used. In other words, the dilution was more pronounced with the single dose (12.5 mg/m^2) as compared to 20 and 25 mg/m^2. Nevertheless, a reduction in the densities of *An. culicifacies* was evident up to 10 years even after withdrawal of spraying in zone I, zone II, and zone III, in comparison to control PHC and was significant at the 5% level ($P < 0.5$). The study revealed that 3 years of continuous indoor residual spraying of deltamethrin was sufficient to produce entomological impact even after 10 years of withdrawal. However, recurring spraying is required with conventional insecticides such DDT and HCH to obtain some impact. The impact of indoor residual spraying of deltamethrin was observed during spraying years on *Cx. quinquefasciatus,* a vector of lymphatic filariasis and a pest mosquito; however, the population quickly recovered and resistance to deltamethrin was detected in this species during the 2nd and 3rd year of spraying (Ansari et al. 1990). The reduction in density of *Cx. quinquefasciatus* was not significant at the 5% level.

Current susceptibility status

Results of susceptibility test are presented in Table 1. It is clear from the table that DDT- and HCH-resistant *An. culicifacies* remained susceptible to deltamethrin even after 3 years of spraying. However, resistance to deltamethrin was detected in *Cx. quinquefasciatus* after 2 years of spraying. The resistance developed in *Cx. quinquefasciatus* during initial spraying reverted back to its original suscep-

Table 1. Susceptibility of *Anopheles culicifacies* and *Culex quinquefasciatus* to deltamethrin and hexachlorocyclohexane (HCH).[1]

Chemical and dosage (mg/m²)	Corrected mortality in subsequent years (%)											
	1987		1988		1990		1992		1994		1995	
	4% DDT	0.025% deltamethrin	4% DDT	0.025% deltamethrin	4% DDT	0.025% deltamethrin	4% DDT	0.025% deltamethrin	4% DDT	0.025% deltamethrin	4% DDT	0.025% deltamethrin
						An. culicifacies						
Deltamethrin												
12.5	20.0 (100)	100.0 (100)	16.0 (100)	100.0 (100)	20.0 (100)	100.0 (100)	12.0 (100)	100.0 (100)	24.0 (100)	100.0 (100)	20.0 (100)	100.0 (100)
20	16.0 (100)	100.0 (100)	12.0 (100)	100.0 (100)	16.0 (100)	100.0 (100)	20.0 (100)	100.0 (100)	16.0 (100)	100.0 (100)	20.0 (100)	100.0 (100)
25	20.0 (100)	100.0 (100)	16.0 (100)	100.0 (100)	20.0 (100)	100.0 (100)	16.0 (100)	100.0 (100)	20.0 (100)	100.0 (100)	16.0 (100)	100.0 (100)
HCH												
200	20.0 (100)	100.0 (100)	20.0 (100)	100.0 (100)	24.0 (100)	100.0 (100)	24.0 (100)	100.0 (100)	24.0 (100)	100.0 (100)	24.0 (100)	100.0 (100)
						Cx. quinquefasciatus						
Deltamethrin												
12.5	0.0 (35)	17.3 (86)	0.0 (45)	10.0 (105)	0.0 (100)	55.0 (100)	0.0 (100)	77.0 (100)	2.0 (100)	78.0 (100)	1.0 (100)	86.0 (100)
20	0.0 (45)	8.3 (130)	0.0 (30)	4.8 (135)	0.0 (100)	62.0 (100)	1.0 (100)	84.0 (100)	0.0 (100)	85.0 (100)	2.0 (100)	92.0 (100)
25	0.0 (125)	18.05 (115)	0.0 (45)	4.6 (75)	1.0 (100)	70.0 (100)	0.0 (100)	89.0 (100)	1.0 (100)	97.0 (100)	0.0 (100)	99.0 (100)
HCH												
200	8.2 (105)	77.5 (136)	10.7 (30)	82.5 (90)	15.0 (100)	95.0 (100)	13.0 (100)	100.0 (100)	19.0 (100)	98.0 (100)	16.0 (100)	98.0 (100)

[1] Figures in parentheses indicate number of mosquitoes tested in 4 replicates. The exposure period for DDT was 1 h and that of deltamethrin was 15 min. Results are calculated according to Abbott's formula (Abbott 1925): % corrected mortality = (% observed mortality − % control mortality)/(100 − % control mortality) × 100.

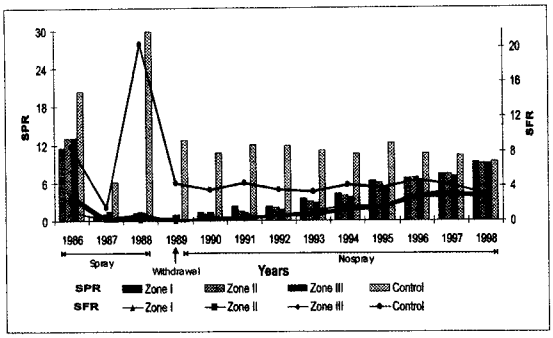

Fig. 2. Annual slide positivity rate and slide falciparum rate from 1986 to 1998 in 1 control and 3 experimental zones.

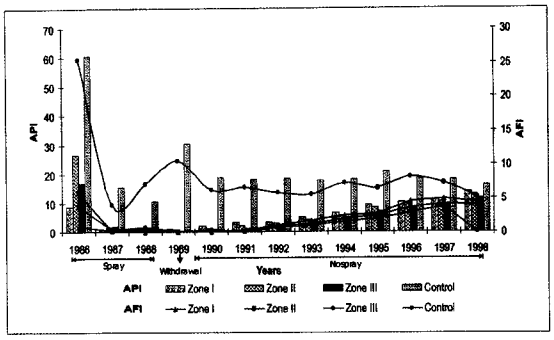

Fig. 3. Annual parasite incidence and annual falciparum incidence from 1986 to 1998 in 1 control and 3 experimental zones.

tibility level when the selection process was withdrawn for about 10 years.

Epidemiological evaluation

Epidemiological indicators are presented in Figs. 2 and 3. The initial indoor residual spraying of deltamethrin at 12.5, 20, and 25 mg/m^2 in zones I, II, and III, respectively, resulted in drastic reduction of all epidemiological indicators during the spraying years (1986–88) in comparison to the control PHC. The residual spraying was completely withdrawn from 1989 onward. However, all indicators (i.e., SPR, SFR, API, and AFI) remained low up to 1993 in all zones, followed by a gradual increase in subsequent years. The impact was highly pronounced when AFI was compared. The AFI remained below 2 up to 5 years in deltamethrin-sprayed areas. Statistical analysis revealed that the difference in both API and AFI up to 1995 was highly significant ($P > 0.005$). The impact gradually started diluting from 1996 onward. Nevertheless, the SFR remained <4 even after 10 years of withdrawal of spraying. Marginal increases in SFR, API, and AFI may be attributed to frequent movement of the population for social and economic reasons. Further relapses in patients with *P. vivax* might have occurred because of insufficient or irregular medication. Meteorological data remained more or less stable during the study period. The mean precipitation in deltamethrin-sprayed areas was 1,147 mm, as compared to 1,063 mm recorded in the control area during 1989–98.

DISCUSSION

The strategy of National Anti Malaria Programme (NAMP) is to carry out indoor residual spraying in rural areas, with DDT, HCH, malathion, or synthetic pyrethroids to interrupt the transmission of malaria. The criteria for change of the insecticides are detection of resistance under field conditions or inadequate effectiveness of the insecticide in a particular district or state. As per insecticide policy, DDT is replaced by HCH and if resistance to both these insecticides is detected, they are replaced by malathion. In areas where resistance to DDT, HCH, and malathion is reported, use of synthetic pyrethroids is recommended. The cost of HCH is almost double that of DDT and, further, malathion or a synthetic pyrethroid are 3 times more costly than DDT, which is still the cheapest insecticide for the malaria control program. A plan was made to phase out use of DDT in India. However, because of existing manufacturing capacity in India and large stockpiles, use of DDT is allowed in the public heath program up to 2008. The DDT replacement options are now restricted to either malathion or synthetic pyrethroids. The cost of these insecticides also is similar. However, malathion is not socially and environmentally acceptable because of its unpleasant odor, staining of walls, and environmental pollution. The present study revealed that the hazardous burden of DDT in the environment can be reduced by selective use of synthetic pyrethroids, which have broad-spectrum activity and appear to be cost-effective, provided that the room coverage is more than 90% and correct dosages are used. The deltamethrin at 20 or 25 mg/m^2 has produced desirable entomological and epidemiological impact, even after withdrawal of insecticide for about 10 years, against *An. culicifacies* (Ansari et al. 2001). However, the impact of deltamethrin on *Cx. quinquefasciatus* diluted rapidly when compared to that of *An. culicifacies,* which may be due to rapid development of resistance in *Cx. quinquefasciatus.* The development of resistance to synthetic pyrethroids is primarily due to the *kdr* gene, a recessive knock-down–resistance gene that also shows cross-resistance to DDT in *Cx. quinquefasciatus* (Halliday and Georghiou, 1985). The species is resistant to DDT, HCH, and malathion in Maharashtra, Gujarat, and Haryana (Sharma and Samnotra 1962, Rajagopal 1977, Sharma 1987); therefore, deltamethrin should be sprayed in multiresistant areas continuously for 3 years and subsequently withdrawn to prevent epidemics up to 10 years and also to reduce the risk of occurrence

of pyrethroid resistance. The cost of indoor residual spraying with different insecticides have been estimated by Phillips and Mills (1991) in Nepal and Konradsen et al. (1999) in Sri Lanka, and recently was reviewed by Walker (2000). Although DDT still emerged as the cheapest insecticide, the environmental impact and human safety of DDT remain major concerns. Moreover, the cost of DDT is increasing because of a decline in production and the cost of synthetic pyrethroids is showing a downward trend. Insecticide and operational costs vary considerably because of differences in production costs, equipment, transportation, wages, and organizational costs. Therefore, the most cost-effective insecticide in any given area or country should be determined by considering local situations. In India, the cost of DDT and synthetic pyrethroids have been worked out by Lal (1999), who reported that DDT (50% wettable powder [WP]) at 1 gm/m^2 and an average house size of 200 m^2 will cost US$0.80 for each spray. However, this does not include the operational cost. According to a recent estimate (NAMP 2002), the annual cost, including operational costs, of DDT is US$1.9 compared to US$5.28 and US$2.86 per house per spray with malathion 25% WP and deltamethrin 2.5 WP, respectively. This indicates that the cost difference between DDT and deltamethrin spray is marginal, but the impact of the 2 insecticides is altogether different. Because *An. culicifacies* is resistant to DDT and HCH, DDT must be sprayed twice in a year at an interval of 10–12 wk on sustained basis to have desirable epidemiological impact. In contrast, an initial 3 years of deltamethrin spraying will continue to produce desired level of impact for about 10 years, even after withdrawal of insecticide.

The calculation of the cost–benefit ratio in terms of collateral benefits and environmental safety indicates that the spraying of synthetic pyrethroids will be more cost-effective than the spraying of DDT. In addition to this, the useful life of insecticide can be prolonged and development of resistance can be avoided. The cost of indoor residual spraying with synthetic pyrethroids can be reduced by selective spraying, taking the village as a unit. *Anopheles culicifacies* is basically a zoophilic species and predominantly feeds on cattle and rests in cattle sheds. Therefore, the cost of insecticide and operational cost can be curtailed further by spraying the insecticide only in human dwelling rooms, as earlier demonstrated by Ansari et al. (1988). The study has clearly revealed that revision of the insecticide policy and strategy of vector control is urgently needed to reduce DDT contamination in the environment and also to reduce the cost of operation and delay the acquisition of resistance.

ACKNOWLEDGMENTS

We are thankful to C. F. Curtis for critically going through the manuscript. The technical assistance of S. N. S. Kachhawaha, K. C. Pushap, Janak Singh, Santosh Vashistha, B. D. Sati, M. D. Tiwari, M. R. Sethi, U. Sreehari, and Sharadchandra Warkade is gratefully acknowledged. We are also thankful to the Director of the Malaria Research Centre for providing necessary facilities to conduct this study.

REFERENCES CITED

Abbott WS. 1925. A method for computing the effectiveness of an insecticide. *J Econom Entomol* 18:265–267.

Ansari MA, Sharma VP, Batra CP, Razdan RK, Mittal PK. 1986. Village scale trial of the impact of deltamethrin (K-othrine) spraying in areas with DDT and HCH resistant *An. culicifacies*. *Indian J Malariol* 23:127–131.

Ansari MA, Sharma VP, Razdan RK, Batra CP, Mittal PK. 1988. The value of spraying cattle sheds in a control programme. *Indian J Malariol* 25:17–22.

Ansari MA, Sharma VP, Razdan RK, Mittal PK. 1990. Field evaluation of deltamethrin against resistant *Anopheles culicifacies* in Distt. Ghaziabad (U.P.) India. *Indian J Malariol* 27:1–13.

Ansari MA, Sharma YD, Roy A, Biswas S, Sharma PK. 2001. Epidemiologic investigations of malaria outbreak in northern Delhi area. *J Am Mosq Control Assoc* 17: 216–220.

Halliday WR, Georghiou GP. 1985. Linkage relationship of the knock down resistance gene (*kdr*) in larvae of *Culex quinquefasciatus* (Diptera: Culicidae). *J Med Entomol* 22:572–576.

Konradsen F, Steele P, Perera D, Van Der Hoch W, Amerasinghe PH, Amerasinghe FP. 1999. Cost of malaria control in Sri Lanka. *Bull WHO* 77:301–309.

Lal S. 1999. *India country report. Issues framework for WHO Action Plan for the implementation of WHA 50.13, with special reference to the gradual phasing out of DDT use for Public Health Purpose SDE/PHE/DP/ 02* Geneva, Switzerland: World Health Organization.

NAMP [National Anti-Malaria Programme]. 2002. *Cost of insecticide and spray in Enhanced Malaria Project areas* India: Directorate of Health Services, Ministry of Health and Family Welfare, Government of India, Delhi.

Phillips MA, Mills AJ. 1991. The operational cost of spraying residual insecticides: a care study for Nepal. *J Trop Med Hyg* 94:130–139.

Pillai MKK. 1996. Vector resistance to insecticide. *Proc Natl Acad Sci India* 66(B):77–95.

Rajagopal R. 1977. Malathion resistance in *Anopheles culicifacies* in Gujarat. *Indian J Med Res* 66:27–28.

Sharma GK. 1987. A critical review of the impact of insecticidal spray under NMEP on malaria situation in India. *J Commun Dis* 19:187–290.

Sharma MID, Samnotra KG. 1962. A note on gamma BHC and dieldrein resistance in *An. culicifacies* Giles in adjoining areas of Gujrat and Maharashtra states. *Bull Natl Soc Indian Malar Mosq Borne Dis* 10:151.

Walker K. 2000. Cost comparison of DDT and alternative insecticides for malaria control. *Med Vet Entomol* 14: 345–354.

WHO [World Health Organization]. 1986. *Carbamate pesticides - a general introduction, IPCS, Environmental Health Criteria* 64. Geneva, Switzerland: World Health Organization.