MINIREVIEW

APPLICATION OF DELTAMETHRIN-IMPREGNATED BEDNETS FOR MOSQUITO AND MALARIA CONTROL IN YUNNAN, CHINA

Zhang Zaixing and Yang Cangjiang

Institute of Malaria Prevention and Treatment, Simao, Yunnan 665000, People's Republic of China

Abstract. The results of research in China in recent years show that: 1) Different laboratory sensitivity of adult *Anopheles minimus, An. sinensis* and *Culex pipiens quinquefasciatus* to deltamethrin exist in Yunnan. Although the range and duration for the use of permethrin and deltamethrin was limited, resistance of *An. minimus, An. sinensis* and *Cx. pipiens quinquefasciatus* to different extents in some areas existed. 2) On walls built with cement and covered with a thin layer of lime on which deltamethrin at a dosage of 0.025 g/m^2 was sprayed, 100% of the mosquitos were stricken down within 3 days, 80% at the 15th day, 50% at the 20th day. The residual effectiveness on the bamboo and wood walls was good and could last for over 40 days, but on the mud walls a mortality of only 40% on the spraying day was observed, indicating that deltamethrin was not suitable for this purpose. Deltamethrin spraying reduced total caught mosquitos within 30 days, but there was no difference between the effects of deltamethrin (0.025 g/m^2) and DDT (2 g/m^2) at the 60th day. Deltamethrin effect on reducing densities of endophilic *An. vagus, An. culicifacies* and exophilic *An. philippinensis* was better than that of DDT (lasting over 60 days), but its effect on semi-endophilic *An. sinensis* lasted only 15 days. Against *An. mininus,* it showed good effects within 20 days but did not last as long as DDT (60 days). Residual deltamethrin and DDT spraying could both control malaria vectors, reduce the infection of infants by malaria, and reduce malaria parasite carrier rates (within 50 days). 3) Laboratory experiments showed that deltamethrin-impregnated bednets at a dosage of 0.015 g/m^2 had a positive effect on *An. minimus.* The residual effect of unwashed deltamethrin-impregnated bednets at a dosage of 0.015 mg/m^2 against *An. sinensis* was apparent and could last for 13 months. When an impregnated bednet was washed for the first time at the 12th month, its mortality effect on *An. sinensis* was reduced quickly to lower than 50%. The residual effect could last for 2-3 months when washed at the 6th month, but was lost when washed for the second time at the 12th month. 4) The effects of the impregnated-bednets on *An. sinensis* were different, even opposite, between different investigations. However, the treated bednets caused the density of *An. minimus* in houses to fall by 67-94%, and the total density in houses and cattle shelters by 67-91%. Moreover, it could shorten the life span of *An. minimus.* It did not work on the outdoor density of *An. minimus.* It is necessary to integrate with other measures, for achieving the desired effect.

INTRODUCTION

Due to the advantages, such as high effectiveness, low toxicity, long-term residual effectiveness, and lack of pollution (Li *et al*, 1988), deltamethrin is widely applied in control of medically important insects. In the early 1980s, it was initially applied to mosquito and malaria control and many successful experiences were reported in China (Li *et al*, 1988; Cheng *et al*, 1991). Some work has been done in this field in Yunnan, especially including observations on the effectiveness in the laboratory and the field. However, large scale application has been limited due to limited finance. This paper reviews some of the applications.

SENSITIVITY OF MOSQUITOS TO DELTAMETHRIN

In 1986, Zhang and Du, in the Institute of Malaria Prevention and Treatment of Yunnan Province, using adult contacting and larvae soaking methods, determined the susceptibility of adult *Anopheles minimus, An. sinensis* and *Culex pipiens quinquefasciatus* (laboratory bred) and their larvae (3rd-stage, 2 days after emergence) to deltamethrin (K-authroing, Rousel-Uclaf). The LC_{50} of the three species were 0.0045%, 0.06% and

0.0352% (y = 1.8563x + 3.7832, y = 7.3531x -2.2281, and y = 22.6298x + 3.562, respectively). The LC_{50} of the larvae of the three species were 0.0445 ppm, 0.0448 ppm, and 0.0557 ppm (y = 2.9539x + 3.0791, y = 3.748x + 2.4243 and y = 6.1247x + 0.4324, respectively), indicating that differences of sensitivity of various mosquitos to deltamethrin existed in Yunnan (Zhang and Du, 1986).

From 1991 to 1994, Du *et al* (1994) using the discriminating dosage method recommended by WHO, investigated susceptibility of mosquitos to 7 insecticides, including deltamethrin. Adults of *An. sinensis* and *An. minimus*, and larvae of *Cx. pipiens quinquefasciatus* and *Cx. triraeniorynchus* were adapted for testing. The discriminating dosages for the former two mosquito species to permathrin and deltamethrin were 0.02% for one hour and 0.01% for 20 minutes, respectively. Discriminating dosages for the latter two mosquitos to permethrin were both 0.001 ppm. The standard was formulated by the National Center for Resistance of Mosquitos to Insecticides. The results showed that of the 22 sites and 23 sites investigated on sensitivity of *An. sinensis* and *An. kunminginensis* to permethrin and deltamethrin, medium and high resistance was found in 16 and 12 sites respectively. Of the 16 and 17 sites surveyed for sensitivity to the 2 insecticides, medium and high resistance were determined in 6 and 3 sites. Of the 3 spots surveyed for sensitivity of *An. minimus* to the two insecticides, all and 1 sites were found to have medium resistance, respectively. Of the 5 sites investigated for sensitivity of *Cx. pipiens quinquefaciatus* to the two insecticides, 1 and 2 sites were found to have medium, and high resistance, respectively. These results indicated that although the range and duration for the use of these two insecticides in Yunnan is limited, resistance to different extents existed in some areas. Further research is needed for defining whether this situation was caused by cross-resistance or natural resistance, in order to modify control activities (Du *et al*, 1994).

DELTAMETHRIN RESIDUAL SPRAYING

Observations on residual effectiveness

On walls built with cement and covered with a thin layer of lime: deltamethrin at a dosage of 0.025 g/m^2 was sprayed on the walls of a hermetic room (3.55 × 2.87 × 3.73 m^3) with the walls built using cement covering with a thin layer of lime. *An. sinensis* and *Cx. pipiens quiquefasciatus*, collected from cattle shelters in villages, were put into the room once per 5 days aiming to observe strike-down within a period of 24 hours. 100% of the mosquitos were stricken down within 3 days, 80% at the 5th day, 50% at the 20th day (Zhang and Du, 1986).

On the walls built with bamboo, wood (fabric boards) and mud: deltamethrin at a dosage of 0.025 g/m^2 was sprayed on the walls built and sensitivity of mosquitos to it was determined by the method of enfored exprosure in a glass funnel for 15 minutes. The residual effectiveness on the bamboo and wood walls was good and could last for over 40 days, but on the mud walls a mortality of only 40% on the spraying day was observed. This indicated that deltamethrin was not suitable for spraying on soil-based walls (Zhang and Du, 1986).

Observations on field spraying effectiveness

Zhang *et al* (1984), observed the effects of deltamethrin (0.025 g/m^2) and DDT (2 g/m^2) residual spraying on bamboo walls for controlling mosquitos and on malaria occurrence in the field. The results revealed that deltamethrin spraying reduced the total caught mosquitos within 30 days, but there was no difference between the effects of the two insecticides at the 60th day. Deltamethrin effect on reducing densities of endophilic *An. vagus*, *An. culicifacies* and exophilic *An. philippinensis* was better than that of DDT (lasting over 60 days), but its effect on semi-endophilic *An. sinensis* lasted only 15 days. Against *An. minimus*, it showed good effects within 20 days but did not last as long as DDT (60 days). Residual deltamethrin and DDT spraying could both control malaria vectors, reduce the infection of infants by malaria, and reduce malaria parasite carrier rates (within 50 days).

Observations by Zhang Yongxin *et al* (unpublished), revealed that in-door and out-door residual deltamethrin (0.025 g/m^2) spraying was not as effective as in-door and out-door residual DDT spraying and the combination of deltamethrin-impregnated bednets (0.015 g/m^2) and out-door residual deltamethrin spraying (0.025 g/m^2) (Zhang *et al*, 1991).

DELTAMETHRIN-IMPREGNATED BEDNETS

Observations on residual effectiveness

The residual effectiveness of deltamethrin-impregnated bednets against *An. minimus* and *An. sinensis* was observed in the laboratory by Huang and Li (1987). Bednets were impregnated at a dosage of 0.015 g/m^2. Before experiment, the residual effect was determined by enforced exposure and bednet-closing method (natural), adapting *An. sinensis* and *An. minimus* bred in the laboratory and aged 5-7 days after emergence. The two kinds of mosquitos were forced to contact for 30 minutes and then removed to recover in order to observe the mortality within 24 hours. The tests were considered to be failure if the mortality was lower than 50%. The results showed that, in three months of observation of *An. minimus*, the mortality of the treatment groups (natural and enforced exposure methods) were 93.3%-100% and 89.1%-90.8%, respectively. In the period, the mortality rates of the control group, by the two methods, were 6.6%-10% and 3.3%-8.3%, respectively. This indicated that deltamethrin-impregnated bednets had a positive effect on *An. minimus* (Huang and Li, 1987).

Thirteen months were taken for observation of the effect of non-washed bednets on *An. sinensis*. The mortality rates of the treatment group, for natural and enforced exposure methods, were 51.7% - 100% and 4.7% - 95% (over 50% in the first 10 months), respectively. In the same period, the mortality rates in the control group were both 0-5.0%. This meant that the residual effect of deltamethrin-impregnated bednets against *An. sinensis* was apparent and could last for 13 months (Huang and Li, 1987).

Observation of the effect of washed bednets against *An. sinensis* also was conducted by Huang and Li (1987). The results revealed that within 3 months after first washing on the 6th month after bednet impregnation, and within the time immediately after the second washing in the 12th month after bednet impregnation, the mortality rates were 68.7%-90% and < 30%, respectively. When an impregnated bednet was washed for the first time at the 12th month, its mortality effect on *An. sinensis* was reduced quickly to lower than 50%, indicating that the residual effect could last for 2-3 months when washed at the 6th month, but was lost when washed for the second time at the 12th month. Exposure to sunlight was also found to reduce the effect (Huang and Li, 1987).

Zhang Yongxin *et al* (unpublished), impregnated bednets at three dosages, *ie*, 0.005, 0.010 and 0.015 g/m^2, respectively, and determined residual effects using *An. sinensis* which were collected from cattle shelters and fed fully at night. Two methods were employed for observation: a) contacting: *An. sinensis* were released into impregnated bednets for 5 minutes and removed to be recovered and bred, in order to observe the mortality within 24 hours, b) natural method: after mosquitos were released into bednets, the ones knocked down and dropping from bednet walls were counted at certain intervals, and the time for knocking half and all mosquitos down was calculated. The results were that all the mosquitos which contacted the 0.010 g/m^2 and 0.015 g/m^2 deltamethrin-impregnated bednets died within 2 hours, but mortality for the mosquitos which contacted the 0.005 g/m^2 bednets was only 69.7%. There was apparently a statistical difference between them. The knocking-down times for the 0.010 g/m^2 and 0.015 g/m^2 bednets were similar, but for the 0.005 g/m^2 bednets, comparatively longer. The effect (residual time of the 0.015 g/m^2 bednets against *An. sinensis*) could last for over 4 months, with mortality of 100%.

Observations on effects in the field

In 1986, Zhang *et al* selected 4 Dai villages, with a total population of 943 and bednet use rate of 85%, to observe the effect of four combinations of insecticides against *An. sinensis*. The four villages were given preventive treatment by deltamethrin-impregnated bednets (0.015 g/m^2) and outdoor deltamethrin spraying (0.025 g/m^2) (Group I), indoor and outdoor DDT spraying (2 g/m^2) (Group II), indoor and outdoor deltamethrin spraying (0.025 g/m^2) (Group III) and control, respectively. *An. sinensis* densities of Group I and II were lower than those before treatment within the 4 months of observation. However, that of Group III was much higher than that before treatment. The vector capacity was affected heavily in Group I and slightly in Group III. Groups I and II mainly acted on *An. sinensis* predicted infectious span and biting behavior. This indicated that the effect in Group I was better than that in Group II. The effect of single deltamethrin-impregnated bednets was not

ideal. It was concluded that in the areas in which there were high bednet-use rates but people refused indoor DDT spraying, the combination of deltamethrin-impregnated bednets and outdoor spraying was an effective alternative for vector control. It could save insecticides and other expenses, compared with overall residual spraying (Zhang *et al*, 1991).

In 1989, Zhang and colleagues, observed the effect of deltamethrin-impregnated bednets (0.015 g/m^2) against *An. sinensis* and *An. minimus*, in 2 villages with a combined population of 1,479 and bednet use rate of 95%. The result for *An. sinensis* was opposite to that mentioned above. It was found that there was no effect against the density of *An. sinensis* in houses, cattle shelters and outdoors; it is assumed this might be associated with local *An. sinensis* behavior (exophily and preference for cattle blood), and the special housing condition, *ie* "two-floor" buildings built with bamboo as walls and grass as roofs, the people living upstairs and cattle downstairs. However, the treated bednets caused the density of *An. minimus* in houses to fall by 67-94%, and the total density in houses and cattle shelters by 67-91%. Moreover, it could shorten the life span of *An. minimus*. However, it did not work on the outdoor density of *An. minimus*. It was suggested that in similar areas, a single application of deltamethrin could not control malaria vectors completely. It is necessary to integrate with other measures to achieve the desired effect (Zhang *et al*, 1991).

In 1989, Li Weiben *et al* (unpublished), conducted an experiment observing the effect of combination of deltamethrin-impregnated bednets (15.3 mg a.i./m^2) and indoor DDT residual spraying (2.59 mg/m^2) against malaria vectors, *An. sinensis* and *An. anthropaphagus*, and malaria prevalence in the northeast part of Yunnan. The results showed that the RPIs of *An. sinensis* and *An. anthropaphagus* were 0.1545 and 0.0008, respectively. Overnight man-biting rates of *An. sinensis* and *An. anthropaphagus* in the experimental area were reduced by 90.70% and 86.11%, respectively, compared with those of the control area. The parous mosquito rates of *An. sinensis* and *An. anthropaphagus* in the experimental area were reduced by 25% and 46.38% respectively, compared with those of the control area. The malaria incidence in the experimental area was reduced by 46.38%, compared with that of the control area. The findings indicated that the combination had decreased mosquito density, man-biting rate and malaria incidence.

APPLICATION IN THE FIELD

Since the early 1980s, deltamethrin-impregnated bednets for control of mosquitos and malaria have been applied fragmentarily in Yunnan. For example, deltamethrin-impregnated and sprayed bednets were applied for protecting populations of 190,682, 387,093, 171,411 and 178,714 at risk of malaria in 1991, 1992, 1993 and 1994 in Yunnan, but DDT spraying for protecting populations of 3,789,131, 3,180,984, 2,603,363, 1,583,863 and at risk of malaria (Zhu 1991; Zhu 1993). The former was only about 1/10 of the latter. Actually, the use of treated bednets was usually integrated with other measures such as DDT spraying, and the effect varied in different places. In 1989, a combination of deltamethrin-impregnated bednets, indoor DDT residual spraying, mass prophylaxis (interval) and presumptive treatment, was employed for control of malaria outbreaks in a vivax and chloroquine-resistant falciparum malaria area, namely Banlao in Cangyan County bordering on Mynmar, leading to a reduction malaria incidence by 81.50% of that in 1988 (Zhang *et al*, 1989). In recent years, deltamethrin-impregnated bednets and DDT residual spraying also were applied in Yanjiang and Xingping counties in which malaria has high prevalence. However, the trend of malaria incidence increase has not been reduced (Fang *et al*, unpublished). From 1983 to 1988, in Daluo, Menghai county, comprehensive measures with emphasis on overall DDT spraying were used. The APIs were between 0.2 and 0.3%. Parasite rates of feverish patients were reduced from 29.4% in 1982 to 7.2% in 1986. Parasite carrier rates were reduced from 8.7% in 1982 to 0.06% in 1986. No *An. minimus* were caught using man-house and man-bait surveys, but the mean density in cattle shelters was 0.5 mosquito/man-hour. In the last 3 years, comprehensive measures were still used but emphasized deltamethrin-impregnated bednets. APIs increased to 0.8% in 1988. Parasite rates of feverish patients and parasite carrier rates increased to 14.7% and 1.5%, respectively. *An. minimus* could be caught in using man-house and man-baits, with average density of 0.5 mosquito man-hour and 0.9 mosquito/

man-night. The density in cattle shelters increased to 1.6 mosquito man-hour. It was assumed to be related to the comprehensive measures with emphasis on overall deltamethrin-impregnated bednets (Li *et al*, 1996).

CONCLUSIONS

In brief, the research and application of deltamethrin-impregnated bednets for control mosquitos and malaria are still limited in scale and the effects are not the same in different areas. This may be associated with the complex status of malaria vectors and their ecological behavior, multi-minority nationality populations and their differently social, economic and behavior. Further research is needed. Moreover, in the areas which minorities live without the habit of bednet use, application of deltamethrin-impregnated bednets for malaria control involves changing living customs. So it is necessary to formulate and conduct education measures in order to have every resident cultivate new and good habits, which can benefit malaria control activities. No deltamethrin-impregnated curtains on windows and doors for mosquito and malaria control have been found in Yunnan until now.

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