Perspective Piece

Controlling Malaria in Western Pacific with Mosquito Nets Treated with Pyrethroids in Village Communities, 1979–1999

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Abstract. Insecticide-treated mosquito nets were first put to practical use in the Western Pacific Region. Less than a decade after conducting workshops and other promotional activities, millions of people were protected by 1989. This occurred before the availability of commercially produced pretreated nets and before global funding for mass net distribution. This paper describes the sequence of steps leading to regional control success. The beginning stages in 1979 recognized that treating torn mosquito nets was a viable control option. Basic net treatment procedures were established by 1983 and workshops were held the next 2 years in China, Cambodia, Laos, Malaysia, Papua New Guinea, Philippines, Solomon Islands, Vanuatu, and Vietnam. Malaria staff became convinced of net benefits and were motivated to impart their knowledge to others. Village inhabitants soaked the nets in washbasins containing permethrin or deltamethrin solution, then dried them horizontally on mats. By the 1990s, the population protected by nets had appreciably increased, and regional malaria cases confirmed by microscopy were markedly reduced. This coincided with commercial interest to mass-produce pretreated mosquito nets for worldwide use.

INTRODUCTION

Considerable information for this article was obtained from data officially submitted by governments to the World Health Organization (WHO) Regional Office in Manila. These included numbers of mosquito nets treated, population protected, malaria cases diagnosed microscopically, and deaths. Annual Regional Committee meeting reports contained country malaria epidemiological data. The regional malaria case reductions were noted to coincide with the expanded use of treated nets. Country and regional malaria meetings included reports by national and WHO staff on small-scale treated net trials showing reductions in malaria cases. The references section of this article lists the key reports containing malaria data and related issues. The annual World Malaria Report of the WHO now includes data on numbers of nets treated and malaria cases reported globally by governments.

Essential activities were necessary to implement a new control approach never before used on a large scale in a country or region. The timeline of activities in Table 1 shows the progressive development of the malaria control program in the Western Pacific using insecticide-treated mosquito nets as a main intervention for malaria control.

Recognizing treated mosquito nets could control malaria mosquitoes, 1979–1982. My first work with WHO included collecting resting engorged blood fed mosquitoes in unsprayed and sprayed huts in Nigeria. Elsewhere, I took part in ground and aerial spraying, mass rearing and release of sterilized mosquitoes, larviciding, and other methods. All were laborious, costly, and temporarily effective. The lesson learned was to be alert to simpler methods.

While visiting a rice field area in southern China in 1979, mosquito nets were widely used in nearby villages to provide some protection against the onslaught of abundant biting mosquitoes. Many mosquitoes engorged with blood, similar to what I saw in Nigeria, were resting inside the torn nets. The sleeping villagers were inadvertently acting as attractants.

I instantly knew I was on to something. A simple and safe way to treat the nets with an effective insecticide would eliminate those mosquitoes and provide great benefits to the affected inhabitants.

While attending a meeting of WHO malaria specialists in Geneva in 1981, an interesting procedure was mentioned. Uniforms and tents of soldiers assigned to the tropics were being treated with pyrethroids at effective doses harmless to humans. This was the key to developing effective mosquito nets to kill mosquitoes. During a 1982 visit to China with WHO malaria staff from Geneva, my workshop presentations included treating mosquito nets with pyrethroids.¹

Training malaria staff to start control activities, 1983–1985. A key point was for national staff to know how to treat the nets and impart this knowledge to others.

The first national workshop in Vanuatu in 1983 focused on treating mosquito nets with permethrin. The technology was simple and nets properly treated with an insecticide not harmful to humans would remain effective even if torn.² Workshops also were held in Cambodia, China, Laos, Malaysia, Papua New Guinea, Philippines, Solomon Islands, and Vietnam. Those attending were public health officers, malaria supervisors, entomologists, sanitarians, community health workers, and other categories of staff. They were encouraged to keep the nets, use them in their homes, and to learn from practical experience the net benefits.

Determining best net treatment methods for village inhabitants, 1983–1985. There were no published reports on treating mosquito nets for malaria control. By trial and error, a suitable technique was developed for village conditions. Setbacks involved using unsuitable containers, improper handling, and drying of nets.

During the first field tests in Papua New Guinea, Vanuatu, and the Solomon Islands nets were treated in plastic bags (Figure 1). This method was not suitable for large-scale operations. Subsequently, a dipping technique was developed and more nets were treated in less time. For dipping and soaking the nets, a dishpan type of plastic or aluminum container holding 15–25 L of permethrin solution was preferred (Figure 2). For nylon nets, a 2% solution achieved a target dosage of 0.5 g/m². About 1 L of the solution was used for

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TABLE 1

Timeline of essential activities to control malaria with mosquito nets treated with insecticide in rural village communities

1979–1982	Recognizing that treated mosquito nets could control malaria mosquitoes
1983–1985	Training malaria staff as key step in starting control activities
	Determining best net treatment methods for village inhabitants
	Minimizing skin and inhalation exposure during net treatment
	Identifying source and size of mosquito nets used for treatment
1985–1989	Achieving support and interest of government health officials and others
1984–1987	Field trials covering populations of 300 to 3,000
1988–1989	Treated nets protecting populations of 40,000 to 5 million
1990–1999	Treated nets protecting populations exceeding 10 million

treating four to five double size nets (11 m²). With two or three dipping stations, about 300 mosquito nets were treated in under 2 hours. After the submerged net was removed from the solution, the excess liquid on the net was allowed to drip into another container (Figure 3). After 1 minute of dripping, the net was placed on mats in a horizontal position to dry (Figure 4). The dosage was randomly determined and dripping time altered as needed.

A permethrin target dosage of 0.5 g/m² provided a range of 0.35–7 g/m². Residual effectiveness varied from 7 to 11 months based on entomological and epidemiological field data. A target dosage of 0.25 g/m² resulted in occasional underdosing and the need to re-treat the nets at intervals that are more frequent.

Minimizing skin and inhalation exposure during net treatment, 1983–1985. It was important that a safe chemical formulation was used and skin exposure limited. Also, women had to be provided answers to various questions such as “is it safe if my baby chews on the net.”

The preferred chemical was permethrin. Permethrin-treated clothing worn without reported side effects was a positive safety factor. Although deltamethrin had good acceptance in China, there were occasional reports of tingling skin sensation in China and Papua New Guinea when families handled nets before complete drying. Those treating were encouraged to use gloves, wear clothing covering arms and legs, and wash

FIGURE 2. Mixing treatment solution in Philippines.

afterwards. Nets left hanging and exposed during the day provided shade, suitable texture for mosquito resting, and complete drying if needed.

Formulations with 50% active ingredient were preferred over 25%. This allowed easier handling in the field and lower costs. Also, adverse skin and inhalation exposure was minimized because less solvent was involved. Sometimes unpleasant side effects with permethrin formulations were reported in Vietnam and China. The problem was traced to unacceptable solvents and corrected by purchasing suitable formulations. In Papua New Guinea, persons dipping nets in large upright containers sometimes experienced headache. Solvent vapor was trapped inside the container. Use of flat, smaller basins corrected that problem.

Identifying source and size of mosquito nets used for treatment, 1983–1985. The project could not move forward without a cheap source of mosquito nets and knowing what was already available in the region.

Mosquito nets were produced in China and owned by millions of families. Papua New Guinea, Solomon Islands, and Vanuatu lacked inexpensive nets. Cheaper polyethylene mosquito nets were obtained from factories in the Philippines, and polyester nets from Thailand. Cotton nets were awkward to treat and dry and not used unless already owned (Figure 5).

Combinations of family (13 m²) and double (11 m²) sized nets were suitable for most situations. About 100 treated

FIGURE 1. Treating mosquito nets in plastic bags in Vanuatu.

FIGURE 3. Dipping mosquito nets in Papua New Guinea.

FIGURE 4. Drying treated mosquito nets in Solomon Islands.

nets protected 250 family members. Normally, two nets were placed inside a house, even though everyone could not sleep under them. The cost of double and family sized nets ranged from US\$2.00 to US\$4.00, and permethrin US\$1.00 to treat a family net at 0.5 g/m². Thus, the cost per house for nets and insecticide did not exceed US\$10.00.

Achieving support and interest of government health officials and others, 1985–1989. To achieve widespread coverage affecting thousands and eventually millions of inhabitants, it was vital to inform and educate government officials and the general public.

The WHO regional office monthly publication “Health and Development” was distributed to all governments in the region and also to many newspapers. Numerous articles on net activities and progress were reported. Lay people not directly involved in health and nongovernmental organizations became interested and motivated to promote net pro-

FIGURE 5. Family with locally purchased mosquito net in Papua New Guinea.

jects. Community participation and primary health care was a common health theme for malaria and other health priorities. Information was provided on net treatment and purchase of insecticide and nets.

The support of major decision makers in the government was important. This included directors of malaria control programs and senior staff of the ministry or department of health. One person of authority who objected to this relatively unknown technique, based on a lack of understanding, could greatly hamper progress. Meetings and discussions in Manila and at the country level helped foster collaboration among key government staff.

Field trials covering populations of 300–3,000, 1984–1987. Adequate preparations were made to determine whether the nets could be conveniently treated by dipping, placed inside houses, and control mosquitoes. These early results were very encouraging.

Prevention of malaria was demonstrated in 1–4 year olds near Madang, Papua New Guinea.² Malaria incidence was reduced from 1.87% to 0.15% in Sichuan, China and from 46.3% to 10.9% in Sabah, Malaysia.³ Mosquito densities also were reduced and families noticed fewer biting mosquitoes. Dead head lice, cockroaches, bedbugs, and flies also were positive observations. The end point of residual effectiveness was indirectly determined in the Solomon Islands by recording dates villages detected a return of head lice, normally about 10 months after treatment. Bioassay tests with wild caught mosquitoes showed that permethrin at 0.5 g/m² and deltamethrin at 25 mg/m² were effective at least 6 months.³

Treated nets protecting populations of 40,000 to 5 million, 1988–1989. Considerable interest was shown by some national malaria control programs to increase population coverage. This was partly attributed to their earlier successful net experiences. An important goal by 1988 was to have every house in a treated village community to have one or two treated nets to reduce vector density, and provide some protection even to those without nets. The most progress was made in China, Solomon Islands, Papua New Guinea, and Vietnam. Table 2 shows number of nets treated, population protected, and reduction in malaria cases that averaged about 80% in China and Vietnam.^{4,5}

Treated nets protecting populations exceeding 10 million, 1990–1999. Further progress was made in population coverage and future planning. Main mosquito malaria vectors controlled were *Anopheles dirus*, *Anopheles Sinensis*, and *Anopheles anthropophagus* in China, *Anopheles minimus* in Vietnam, Cambodia, and Laos, *Anopheles balabacensis* and *Anopheles maculatus* in Malaysia, *Anopheles flavirostris* in Philippines, and *Anopheles farauti* in Papua New Guinea, Solomon Islands, and Vanuatu. Treated nets provided some health benefits in areas where exophilic vectors mainly bit and rested outdoors, such as *Anopheles dirus* in Hainan, China.⁵ Vector densities were reduced, and infants, mothers, and young children often went to bed earlier than other family members with less exposure to biting mosquitoes. The malaria parasites observed in malaria cases confirmed by microscopy were *Plasmodium falciparum* and *Plasmodium vivax*.

All nine malaria endemic countries by 1999 had implemented treated mosquito net control activities, combined with diagnosis and treatment of malaria patients. About a decade after the first workshop in Vanuatu, millions of such nets were used. Table 3 shows data for 1995.⁶ It excludes China where

TABLE 2

Approximate numbers of pyrethroid-treated mosquito nets used for malaria control, 1988

Country	Number nets treated	Population protected	Percent reduction in malaria cases
China	2,400,000	5,460,000	63–98 in Jiangsu, Hainan, and Sichuan Provinces
Solomon Islands	20,000	50,000	72
Papua New Guinea	20,000	50,000	62
Vietnam	16,000	40,000	80 in forest, mountain, and coastal areas

mass mobilization treatments sometimes involved millions of nets.

Vietnam had 10 million inhabitants protected by 1996.⁷ Vanuatu covered 70% of the population at risk by 1997 and planned complete coverage by 1999. The northeastern provinces of Cambodia proceeded toward complete coverage by 1999 (Figure 6).

Constraints. Effective malaria control was difficult to maintain in remote rural areas of Cambodia and Laos, where transmission was intense and mortality was high. Epidemics occurred at hard-to-reach high altitudes in Papua New Guinea, and Solomon Islands had problems controlling relapse *vivax* cases.

Chemical formulations used for village treatments were not long lasting and nets ideally required retreatment at least once a year. The pretreated commercial nets that eventually became available provided a more rapid placement of nets and a longer residual lasting several years.

DISCUSSION

Workshops and modest provision of nets and insecticide were essential starting points to begin community control activities in villages. Malaria staff realized that net treatment operations had advantages over indoor house spraying. The simplicity, speed, minimal supervision, and lower costs were readily apparent.⁸ Villagers with net in hand did the work. Early resistance to and skepticism on using treated nets to control malaria were overcome by reductions in malaria cases and infant mortality.

A detailed study of malaria case reductions specifically attributed to treated nets was not done. However, drugs were used mainly to treat malaria cases and prevent death. Indoor spray coverage was on decline and, except for special situations, was being phased out. The main control interven-

FIGURE 6. Preparing mosquito nets for treatment in Cambodia.

tions were treated nets. A recent comprehensive study covering a 15-year period in Africa concluded that 68% of the 600 million malaria cases prevented were attributed to treated nets.⁹ A reasonable assumption in the Western Pacific is that hundreds of thousands of cases were prevented and probably as many as several million or more.

The current WHO-recommended vector control measures for malaria control and prevention are treated mosquito nets and indoor residual sprays. Free-of-charge long-lasting insecticide-treated nets are the preferred form of treated nets. Village treatments in the Western Pacific are becoming less frequent but could resume if funding constraints occurred and high-transmission areas remained uncontrolled. *Plasmodium falciparum* has been particularly difficult to treat in Cambodia and artemisinin resistance occurs. Long-lasting insecticide-treated mosquito nets are being distributed there in a collaborative elimination strategy involving neighboring countries.

CONCLUSIONS

A marked reduction in the number of malaria cases was confirmed by microscopy. There were 4.5 million cases in the Western Pacific in 1977, 1.3 million in 1986, and 0.5 million in 1996.⁷ Malaria deaths were also markedly reduced and Vietnam, for instance, reported 4,646 in 1991 but only 348 in 1995.⁶ In China, malaria was mostly controlled.¹⁰

These control successes eventually led to marked improvements in treated mosquito net delivery and residual effectiveness. The vast numbers of pretreated long-lasting insecticide-treated mosquito nets commercially produced and distributed annually have had a tremendous impact in reducing malaria cases and deaths, mainly in Africa. The rural village populations of the Southwest Pacific Island countries of the Western Pacific, who agreed to and participated in the first field trials with treated nets, indirectly contributed to the worldwide malaria control efforts.

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TABLE 3

Numbers of treated mosquito nets and malaria cases, 1995

Country	Number nets treated	Population protected with treated nets	Number of microscopically diagnosed cases
Cambodia	20,000	54,475	78,374
Laos	10,000	30,000	53,614
Malaysia	127,351	255,016	59,208
Papua New Guinea	272,765	818,295	99,000
Philippines	259,935	779,805	56,852
Solomon Islands	209,558	272,425	118,521
Vanuatu	65,419	85,687	8,318
Vietnam	3,068,709	7,978,644	100,116
Total	4,033,737	10,274,347	621,191*

*Includes 47,188 cases reported by China.

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