COST-EFFECTIVENESS AND SUSTAINABILITY OF LAMBDACYHALOTHRIN-
TREATED MOSQUITO NETS IN COMPARISON TO DDT SPRAYING FOR MALARIA
CONTROL IN WESTERN THAILAND

PIROM KAMOLRATANAKUL, PIYARAT BUTRAPORN, MALINEE PRASITTISUK, CHUSAK PRASITTISUK, AND
KAEMTHONG INDARATNA

Faculty of Medicine, Chulalongkorn University, Bangkok, Thailand; Faculty of Tropical Medicine, Mahidol University, Bangkok,
Thailand; World Health Organization Regional Office for South East Asia, New Dehli, India; Faculty of Economics,
Chulalongkorn University, Bangkok, Thailand; Malaria Division, Ministry of Public Health, Bangkok, Thailand

Abstract. The cost-effectiveness of lambdacyhalothrin-treated nets in comparison with conventional DDT spraying
for malaria control among migrant populations was evaluated in a malaria hyperendemic area along the Thai-Myanmar
border. Ten hamlets of 243 houses with 948 inhabitants were given only treated nets. Twelve hamlets of 294 houses
and 1,315 population were in the DDT area, and another 6 hamlets with 171 houses and 695 inhabitants were in the
non–DDT-treated area. The impregnated net program was most cost-effective (US$1.54 per 1 case of prevented
malaria). Spraying with DDT was more cost-effective than malaria surveillance alone ($1.87 versus $2.50 per 1 case
of prevented malaria). These data suggest that personal protection measures with insecticide-impregnated mosquito
net are justified in their use to control malaria in highly malaria-endemic areas in western Thailand.

INTRODUCTION

Malaria continues to be an important public health problem in Thailand today.1 The situation is particularly critical
among the high-risk groups of migrant populations along international borders, causing multidrug-resistant Plasmodi-
um falciparum to spread through most parts of the country.2 Therefore, appropriate malaria control strategies with em-
phasis on organizational, economic, and cultural aspects are urgently needed.

Residual DDT indoor spraying has been used as a national malaria control measure in Thailand since 1940.3 If labor
and supervision costs are considered, the insecticide spray-
ing programs would constitute at least half of the total ma-
laria budget. However, control of malaria vectors by expen-
sive conventional DDT spraying has encountered serious set-
backs for 2 reasons: a low level of acceptability by com-
munities; and a failure for DDT to sufficiently interrupt malaria transmission in the highly endemic areas.4 Therefore,
establishing locally cost-effective malaria control measures for use by communities as part of a primary health care
strategy to replace DDT spraying would be of major public health significance.

Among available control measures, personal protection by means of insecticide-impregnated bed nets has shown prom-
ising results in a number of countries.5–35 Moreover, the use of impregnated bed nets has been proved appropriate both
in terms of acceptability and affordability among migrant workers in eastern Thailand.39 This control measure was
found to be useful among migrant populations along the frontier areas because the community can treat nets with
appropriate chemicals under the direction of local health workers, which can then easily be carried to the forest or
farm hut.

Although pyrethroid-treated mosquito nets are gaining in popularity, questions remain as to their effectiveness, cost-
effectiveness, acceptability, and sustainability. It is not known whether treated mosquito nets can control malaria
better than DDT indoor residual spraying.

Thus, we have compared the cost-effectiveness of lamb-
dacyhalothrin-treated mosquito nets with conventional DDT
spraying for malaria control among migrant populations in
a highly malaria endemic area along the Thai-Myanmar bor-
der. The impact of this intervention on epidemiological as-
pects of malaria will be published elsewhere.

MATERIALS AND METHODS

Study area. This study was conducted at 6 villages in 2
subdistricts of the Mae-Ramard District, Tak Province, be-
tween February 1993 and January 1994. Study sites were
located at the western border of Thailand with Myanmar, at
latitude 16°55′ and longitude 98°40′ in the forest fringing
several small valleys and hills, with an altitude ranging 400–
800 m above sea level. These areas are within a government-
conserved forest area inhabited by Karen hill tribes. The area
consists of houses and huts, scattered in the form of hamlets,
∼2–5 km apart, mostly inaccessible by car. Sites were cho-
sen on the basis of high malaria endemicity (annual inci-
dence > 20,000 per 100,000 population) and the similarity
of malaria vectors, ecology, topography, and terrain of each
hamlet.

Allocation. Twenty-eight hamlets of similar malaria inci-
dence were divided into 3 groups: a net area, a DDT area,
and a control area. The net area was located in Villages 2
and 4 of the Sam-Muen Subdistrict, comprising 10 hamlets,
243 houses, and 948 inhabitants. The DDT area was located in
Village 1 and 3 of Sam-Muen Subdistrict, comprising 12
hamlets, 294 houses, and 1,315 inhabitants. The control area
consisted of 6 hamlets in Villages 7 and 10 of the Mae-Jarao
Subdistrict and had with 171 houses and 695 inhabitants.
Anopheles minimus and Anopheles dirus were the major ma-
laria vectors in all 3 study areas.

Baseline data. At the outset of the study, baseline epi-
demiologic, social, economic, and entomological parameters
were collected as previously described by Prasittisuk and
others (unpublished data). Thick blood smears were obtained
from all subjects and examined for malaria parasites. If pos-
itive, the subject received treatment in accordance with the
policies of the Malaria Division, Ministry of Public Health.
Informed consent was obtained from all human adult partic-
ipants and from parents or legal guardians of minors. This
TABLE 1
Comparison of baseline information obtained from the 3 experimental groups

<table>
<thead>
<tr>
<th>Baseline information</th>
<th>DDT spraying</th>
<th>Insecticide-impregnated bed nets</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of subjects</td>
<td>1,423</td>
<td>1,034</td>
<td>757</td>
</tr>
<tr>
<td>No. of households</td>
<td>265</td>
<td>202</td>
<td>140</td>
</tr>
<tr>
<td>Average no. of subjects per household*</td>
<td>5.4</td>
<td>5.1</td>
<td>5.4</td>
</tr>
<tr>
<td>Age in years, mean ± standard deviation*</td>
<td>21.3 ± 17.8</td>
<td>20.9 ± 17.7</td>
<td>22.3 ± 17.5</td>
</tr>
<tr>
<td>Sex ratio (M/F)*</td>
<td>1.03:1.00</td>
<td>1.01:1.00</td>
<td>0.96:1.00</td>
</tr>
<tr>
<td>Annual parasite incidence per 1,000 (1988–1993)†</td>
<td>100–400</td>
<td>100–400</td>
<td>100–400</td>
</tr>
</tbody>
</table>

* Not statistically significant.
† Prasittisuk M, unpublished data.

Study was approved by the ethics committee of the Faculty of Medicine, Chulalongkorn University.

Interventions. Impregnation of mosquito nets. By the baseline survey, mosquito nets available within each household were recorded before the intervention. The community was prepared by encouraging villagers to wash their own nets and allowing them to dry properly for 1–2 days before impregnation with 20 mg active ingredient (a.i.) /m² lambdacyhalothrin in the form of an emulsifiable concentrate containing 2.5% active ingredient. The method of impregnation modified from Shreck and Self 36 and as described by Prasittisuk and others 37 was used. In addition, new impregnated mosquito nets were provided to cover the whole population in the net area.

Spraying with DDT. Spraying with DDT was carried out indoors as a residual spray cover in the 12 hamlets as previously described with 2 g a.i./m². The spraying operations were implemented similarly to the normal practice of malaria control.

Control group. Malaria surveillance was carried out in the 3 study areas in terms of passive case detection, including the control group, by using health care facilities at all levels of the health care system (provincial hospital, district hospital, 5 local health centers, malaria sector, and 3 malaria clinics).

Compliance monitoring. The subjects’ compliance in using the net was monitored qualitatively (observation with full participation). The results of this study will be reported elsewhere.

Evaluation of efficacy. The number of subjects in the study area who could potentially be prevented from contracting malaria was used as an indicator to evaluate the program effectiveness. Because of the unequal numbers of subjects in the 3 study groups, we had to calculate the expected number of subjects with malaria by adjusting the number of subjects enrolled from observations for the standard population (number of subjects in the DDT spraying groups).

Identification and estimate of provider costs. Costs were determined for fiscal year 1994 (October 1993 to September 1994) and expressed in U.S. dollars. The major viewpoint adopted in this study was that of the Malaria Division, Ministry of Public Health, Thailand. This perspective was selected because the Malaria Division is the final decision-maker in the funding of malaria control programs and hence responsible for the organization and administration of all medical and public health services for malaria in the country.

The cost incurred by the provider was the real cost of delivering the service to the malaria patients at all levels of the health care system in the study areas during fiscal year 1994. The total provider cost in each health care facility was be calculated from labor, material, and capital cost. The total direct cost is the sum of those 3 components. This study applied the direct distribution method as a method of cost allocation to each cost center. 38,39

In this study, cost and effects are largely immediate, leaving the cost-effectiveness ratio relatively unaffected by the discount rate. Therefore, no attempt was made to adjust cost and effects for time.

For statistical evaluation of the effectiveness, the level of significance was calculated by the chi-square test.

RESULTS

Comparability of baseline data among the 3 study groups. A comparison between important baseline progno-
and follow-up, and cost of organization, administration, included cost of blood smear examination, cost of treatment. Lariam surveillance in terms of passive case detection, which when adjusted for the standard population. The cost of malariac spraying was 2.4 times higher than that of net impregnation.

The details of this study will be described elsewhere (Prasittisuk M and others, unpublished data). In brief, among the 1,034 people who used impregnated nets, 61 (6%) had malaria compared with 68 (5%) of 1,423 in the DDT spraying group and 97 (13%) of 757 in the control group (P < 0.0001, by chi-square test) (Table 2). One hundred fifteen episodes of malaria were found among subjects in the treated bed net group compared with 136 in the DDT spraying group and 275 in the control group (P < 0.0001).

In terms of species-specific parasitemia, 77 episodes of *P. falciparum* parasitemias were seen in the treated bed net group (72%) and 215 of 757 (78%) in the control group (P < 0.0001). Thirty-eight episodes (28%) of *P. vivax* parasitemia were found in the impregnated bed net and DDT spraying groups compared with 60 episodes (21.8%) in the control group (P < 0.0001).

Costs. Total provider costs of DDT spraying and impregnation of nets are presented in Table 3. The cost of DDT spraying versus the cost of impregnation of nets is shown in Table 1.

The critical situation of malaria-prone areas along international borders should be vigorously addressed by appropriate, cost-effective control measures for malaria. Insecticide-impregnated mosquito nets, impregnated, for example, with pyrethroids, will probably be the most cost-effective, feasible, and acceptable means in these areas because nets

### Table 3

<table>
<thead>
<tr>
<th>Component of cost</th>
<th>Cost of DDT spraying (Amount)</th>
<th>Cost of impregnation of nets (Amount)</th>
<th>Cost of impregnation of nets (Amount)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>440.10</td>
<td>238.45</td>
<td>66.59</td>
</tr>
<tr>
<td>Material</td>
<td>400.39</td>
<td>119.62</td>
<td>33.41</td>
</tr>
<tr>
<td>Capital</td>
<td>3.58.69</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>1,199.18</td>
<td>358.07</td>
<td>100.00</td>
</tr>
<tr>
<td>Total cost for standard population</td>
<td>1,199.18</td>
<td>492.71</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4**

<table>
<thead>
<tr>
<th>Health care facilities</th>
<th>DDT spraying</th>
<th>Insecticide-impregnated bed nets</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. episodes</td>
<td>Total cost</td>
<td>No. episodes</td>
</tr>
<tr>
<td>At malaria clinic</td>
<td>544</td>
<td>1,089</td>
<td>2,089</td>
</tr>
<tr>
<td>Positive cases</td>
<td>51</td>
<td>94</td>
<td>474</td>
</tr>
<tr>
<td><em>Plasmodium falciparum</em></td>
<td>4.36</td>
<td>117.75</td>
<td>239.87</td>
</tr>
<tr>
<td><em>Plasmodium vivax</em></td>
<td>2.95</td>
<td>70.82</td>
<td>115.08</td>
</tr>
<tr>
<td>Negative cases</td>
<td>0.52</td>
<td>27</td>
<td>79.12</td>
</tr>
<tr>
<td>At health centers</td>
<td>226</td>
<td>37</td>
<td>1,615</td>
</tr>
<tr>
<td>Positive cases</td>
<td>43</td>
<td>37</td>
<td>4</td>
</tr>
<tr>
<td><em>P. falciparum</em></td>
<td>2.93</td>
<td>120.14</td>
<td>27</td>
</tr>
<tr>
<td><em>P. vivax</em></td>
<td>1.52</td>
<td>3.04</td>
<td>15.20</td>
</tr>
<tr>
<td>Negative cases</td>
<td>1.30</td>
<td>237.35</td>
<td>167.31</td>
</tr>
<tr>
<td>At district hospital</td>
<td>206</td>
<td>168</td>
<td>1200</td>
</tr>
<tr>
<td>Positive cases</td>
<td>42</td>
<td>28</td>
<td>39</td>
</tr>
<tr>
<td><em>P. falciparum</em></td>
<td>3.96</td>
<td>118.75</td>
<td>24</td>
</tr>
<tr>
<td><em>P. vivax</em></td>
<td>2.55</td>
<td>30.57</td>
<td>10.19</td>
</tr>
<tr>
<td>Negative cases</td>
<td>2.33</td>
<td>381.30</td>
<td>325.50</td>
</tr>
<tr>
<td>Total cost</td>
<td>1,337.56</td>
<td>1,567.65</td>
<td>3,108.32</td>
</tr>
</tbody>
</table>

*Adjusted for standard population.

### Table 5

<table>
<thead>
<tr>
<th>Group</th>
<th>Impregnation measure</th>
<th>DDT spraying</th>
<th>Insecticide-impregnated bed net</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impregnation of nets</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>DDT spraying</td>
<td>1,199.18</td>
<td>0</td>
<td>3,108.32</td>
<td>0</td>
</tr>
<tr>
<td>Surveillance (PCD)</td>
<td>1,377.56</td>
<td>1,567.65</td>
<td>3,108.32</td>
<td>0</td>
</tr>
<tr>
<td>Total cost</td>
<td>2,536.74</td>
<td>2,060.36</td>
<td>3,108.32</td>
<td>0</td>
</tr>
</tbody>
</table>

PCD = passive case detection.

**DISCUSSION**

The results of this study indicate that insecticide-impregnated bed nets are cost-effective for preventing malaria in western Thailand and are well accepted by the resident populations there. It is of substantial importance that the impregnated bed nets were more cost-effective than residual DDT spraying or malaria surveillance alone for malaria control. Most Karen hamlets are located in the forest along the border and hence are generally exposed to high malaria endemicity. The critical situation of malaria-prone areas along international borders should be vigorously addressed by appropriate, cost-effective control measures for malaria. Insecticide-impregnated mosquito nets, impregnated, for example, with pyrethroids, will probably be the most cost-effective, feasible, and acceptable means in these areas because nets
are already available and widely used. Karen people usually go to sleep around 8 PM and remain inside their houses after sunset. However, they rise early, around 4 AM. This cultural characteristic supports the use of mosquito nets for malaria control, considering that the peaks of An. dirus and An. minimus are at around 8 PM and also from 10 PM to midnight. Malaria infection may be contracted during the early morning upon emerging from the bed net.

Although the analysis showed that the impregnated bed net program was the most cost-effective, certain measures are required to ensure sustainability of the program. These malaria control activities should be integrated into the primary health care system in accordance with local conditions. A mosquito net fund can be set up at the village level under the management of the Village Development Committee. A villager can thus buy a net at a reasonable price; payment in installments may possibly be arranged. For villagers unable to pay, mosquito nets may be provided in return for labor (e.g., constructing roads and planting trees), which also benefits the community. Insecticide impregnation of nets can be arranged through community activities. Impregnation can be carried out annually before the malaria transmission season. Such a strategy is likely to enhance sustainability.

Bed nets were not included as the capital costs in this study because the major viewpoints adopted in this study were those of the Malaria Division, Ministry of Public Health (provider perspective). The Ministry of Public Health did not provide free bed nets to the villagers but provided free impregnation of the nets.

There are probably 3 major methods to treat mosquito nets: spraying, dipping, and the individual soaking method. The spraying method requires experienced personnel. It is also difficult to obtain an exact dosage of insecticides. Large amounts of the budget are wasted on labor and material costs due to insecticide loss during spraying. Mass dipping requires that several mosquito nets are impregnated together. This might be disadvantageous in that people may reject the notion of having their nets mingled with those of others. This method may not be applicable to Thai people. Therefore, in this project, we decided to use the individual-soaking technique. This method can be performed individually in a suitably sized polythene bag and also reduces contamination of workers with insecticide. We found this method to be simple and convenient, and the villagers were able to treat their nets by themselves. The residual effect of 20 mg a.i./m² of lambdacyhalothrin on polyester nets lasted for more than 12 months. Therefore, impregnation of nets may be performed only once a year at the beginning of transmission season.

The limitation of this study is the quasieperimental study design that lacks randomization.60 The most appropriate design for assessing the effectiveness of an intervention is randomized, double-blind clinical trial. This was not a feasible approach in this study as a result of operational difficulties. Therefore, it is difficult to interpret with the highest possible confidence the observed effects of the different intervention groups. However, except for the number of subjects in each group, the 3 groups we studied were comparable.

Compared with the control group, there was an apparent reduction in malaria morbidity in the DDT group. However, we contend that administration of DDT for vector control operations in Thailand should be terminated for several reasons: e.g., residual DDT spraying was not sufficient to interrupt the transmission of malaria. In addition, DDT dirty houses and cannot cover migrant populations. Furthermore, the public’s increased concern with environmental contamination and toxicity to humans and animals has led many countries to ban the use of DDT.

It has become clear that any given single method cannot successfully control vector-borne diseases. Locally appropriate vector-control techniques must be developed for areas where residual house spraying is not practical. Self-protection is presently found to be the most suitable method for reducing transmission. Impregnated nets for personal protection are popular in many parts of the world and are used by members of various societies.

This study exemplified how cooperation among policymakers, administrators, implementers, and university researchers can lead to the implementation of health policy that is based on research findings. The results of this study have contributed to the malaria control program by recommending replacement of residual house spraying for vector control in high-risk areas with personal protection measures, particularly insecticide-impregnated mosquito nets.

Acknowledgments: We thank Dr. David Evans from the World Health Organization, Mongkol Unkarsithongkul, Jeeraput Sirichaisinthop, and Uthai Tritan from the Regional Malaria Centre 1, and health personnel at Malaria Zone 11 and Malaria Sectors 3 and 11 for their assistance.

Financial support: This study was supported in part to Centre for Disease Vector Control Department of Communicable Disease Control through Research Strengthening Grant (RSG) from WHO/World Bank/UNDP Special Programme for Research and Training in Tropical Diseases.

Authors’ addresses: Pirom Kamolratanakul, Faculty of Medicine, Chulalongkorn University, Bangkok 10330, Thailand. Piyarat Bstraporn, Faculty of Tropical Medicine, Mahidol University, Bangkok

---

Table 6
Cost-effectiveness analysis of mosquito control in the 3 study groups

<table>
<thead>
<tr>
<th>Measured outcome</th>
<th>DDT spraying</th>
<th>Insecticide-</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of subjects</td>
<td>1,423</td>
<td>1,034</td>
<td>757</td>
</tr>
<tr>
<td>No. of subjects with malaria (observed)</td>
<td>68</td>
<td>61</td>
<td>97</td>
</tr>
<tr>
<td>Expected no. of subjects with malaria (at rate in standard population)</td>
<td>68</td>
<td>84</td>
<td>182</td>
</tr>
<tr>
<td>Expected no. of subjects protected from malaria</td>
<td>1,355</td>
<td>1,339</td>
<td>1,241</td>
</tr>
<tr>
<td>Total cost (US$)</td>
<td>2,536.74</td>
<td>2,060.36</td>
<td>3,108.32</td>
</tr>
<tr>
<td>Cost per single case of prevented malaria (US$)</td>
<td>1.87</td>
<td>1.54</td>
<td>2.50</td>
</tr>
</tbody>
</table>
REFERENCES


