RECENT RESEARCH ON IMPREGNATED MOSQUITO NETS

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ABSTRACT. The present status of impregnated mosquito nets and other impregnated materials is discussed. Research projects which have produced most of the publications on this subject were conducted in areas in Africa with relatively high endemicity of malaria. In these areas, usage of impregnated mosquito nets caused substantial reductions in the sporozoite inoculation rates and some reduction in incidence of malaria attacks. However, there was little or no reduction in parasite rates in the human population. In several countries in Asia and the Pacific, vector control with impregnated mosquito nets has been introduced on a large scale, thus proving its affordability and compatability with local customs in these countries. Substantial reductions in malaria parasite rates have been obtained in areas with low levels of malaria transmission. In order to develop the vector control method which is most appropriate for each area, much more research is needed on the technical and organizational aspects of vector control with impregnated mosquito nets. Examples are given of data already available as well as an indication of gaps in knowledge which still exist and will need more attention.

INTRODUCTION

Mosquito nets and their impregnation with insecticides or repellents to improve their effectiveness has a long history (Grothaus et al. 1972, 1974; Lindsay and Gibson 1988). Interest in the impregnation of mosquito nets has revived in recent years. Now that pyrethroids are available this method is considered by many people to be the most promising advance in malaria control in 40 years. Furthermore, it seems to be the most rational way to use pyrethroids against malaria vectors because female mosquitoes are attracted to make contact with occupied mosquito nets by the odor of the occupant.

Although there have been many claims that impregnated nets are effective, available data do not convince everybody. Careful analysis of the trials which have been carried out should take into account the variables in the makeup of impregnated mosquito nets, the different methodologies used to monitor the efficacy and the conditions under which the studies were carried out. The first section of this review discusses whether the studies which have so far been published in the scientific literature are representative of those countries where large scale applications are now being carried out or are likely to be carried out. Subsequently, the research data on the efficacy of impregnated mosquito nets on the vector and the disease are discussed. This is followed by a discussion of the technical information available on impregnated mosquito nets and possible ways to improve their efficacy. Impregnated mosquito nets are often referred to as an appropriate technology for vector control. The next section of this review deals with the question under what circumstances this might be true and discusses alternative impregnated materials which might be equally or more appropriate for reducing vector-borne diseases. Finally, a few conclusions may be drawn on the potential of impregnated mosquito nets in reducing malaria under different circumstances and the areas which should receive priority in future research.

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GEOGRAPHICAL DISTRIBUTION OF ACTIVITIES WITH IMPREGNATED MOSQUITO NETS

The geographical distribution of research trials and application of impregnated mosquito nets are shown in Table 1. There are very few reports from South America. A majority of the research trials in Africa which have been published have included less than 1,000 people per trial. The bed-net activities in Asian and Pacific countries have been on a much larger scale, often at an operational level. However, only a very limited number of publications have been produced though more are now becoming available from China (Li et al. 1988, 1989). It appears that impregnated mosquito nets are more acceptable and affordable to both national vector control staff and communities in Asia and the Pacific than in Africa. In view of the differences between regions, the extrapolation of research data to countries where no research has been carried out should be done with caution.

EVALUATION OF RESEARCH TRIALS AND MODE OF ACTION

The effects of pyrethroid-impregnated netting have been studied in laboratory trials, experimental hut studies and village scale trials. It can be concluded that impregnated mosquito nets may deter mosquitoes from entering a house (Darriet et al. 1984) though the mechanism by which they do so is still unclear. The pyrethroid irritates those which do enter and make contact

Table 1. Geographical distribution of field trials and large scale applications of impregnated mosquito nets (based on published data or data made available to the World Health Organization)

Country	Approximate number of people protected
Africa	
Burkina Faso[1] a)	<1,000
b)	<1,000
Cameroon	<1,000
Kenya	<1,000
Mali	<1,000
Tanzania	1,000
The Gambia	<1,000
Asia and the Pacific	
Bangladesh	1,000
China	5,460,000
India	1,800
Indonesia	<1,000
Kampuchea	<1,000
Laos	300
Malaysia	1,000
Papua New Guinea	50,000
Philippines	1,500
Solomon Islands	50,000
Thailand	<1,000
Vanuatu	150
Viet Nam	40,000
Western Samoa	<1,000
South America	
Brazil[2]	2,000
Suriname[3]	<1,000
Venezuela	<1,000

[1] a) Trials with impregnated mosquito nets. b) Trial with impregnated curtains and eave strips.
[2] Trials with impregnated sheeting for houses without walls.
[3] Trials with impregnated wide mesh gauze which covers openings in the walls of houses.

with the net. The irritant effect inhibits the search for a bloodmeal and causes an exodus of mosquitoes from the house (Lines et al. 1987, Rozendaal et al. 1989). Some of these mosquitoes pick up insecticide and will die or show abnormal behavior (Lines et al. 1987, Li et al. 1987). When many impregnated nets are in use, these effects cause a marked drop in the sporozoite rate (Carnevale et al. 1988, Curtis et al. 1989) and human blood index (Charlwood and Graves 1987), and sometimes even a measurable reduction in mosquito biting densities (Li et al. 1988). Fewer infective bites results in a reduction in malaria attacks (Snow et al. 1988) and sometimes in a reduction in parasite rates (Li et al. 1988).

It can be expected that impregnated mosquito nets will be more effective against mosquitoes which: a) bite indoors, b) have a peak biting activity at or after midnight when most people are asleep and c) are not exclusively anthropophilic and so, if diverted from biting a human, are likely to bite an animal.

COMMUNITY VERSUS INDIVIDUAL PROTECTION

Trials in The Gambia (Snow et al. 1988) showed that children sleeping under impregnated mosquito nets had 63% fewer malaria attacks in a trial in which everyone in certain villages was given treated nets. This may be compared with a trial in which only 10% of the children in one village had had their nets treated where the reduction in number of attacks was only 41% (Snow et al. 1987b) The difference between these results was presumably due to reduced mosquito survival when all villagers use impregnated nets.

Nonusers of impregnated mosquito nets may also receive protection of a more direct kind when other people sleep under impregnated nets. Lines et al. (1987) showed that in Tanzania people sleeping in the same room as a person sleeping under a treated net received fewer mosquito bites than when they shared the room with a person without a net. This can be explained by the excito-repellent effect on mosquitoes which has been observed in all the entomological studies. People sleeping in other houses or out of doors in the same village may also receive protection because of the mortality caused by the nets and the observed lower sporozoite rate in the mosquito population. However, with treatments which are more effective in repelling than in killing mosquitoes, the use of treated nets could conceivably increase the risk of infection among unprotected people.

EFFECTIVENESS OF IMPREGNATED MOSQUITO NETS IN RELATION TO THE LEVEL OF MALARIA ENDEMICITY

Entomological baseline data are essential for an understanding of the mode of action of the vector control method. Reducing the vector's life expectancy or feeding success or diverting it from biting humans is likely to reduce the incidence of new infections (Graves et al. 1987, Hii et al. 1987), but does not necessarily result in a reduction of the prevalence of the disease. The vectorial capacity often has to be reduced very markedly in order to be able to measure any effect on the prevalence of the infection (see Fig. 1). The reduction required will depend on the nature of the disease, (e.g., malaria or filariasis have very different characteristics), levels of transmission and endemicity and the immunity of the human population.

In some areas of holoendemic malaria with no vector control programs, people receive on average more than one sporozoite infective bite per night, and each of these infections may persist concurrently (superinfection) for many days in the absence of widespread drug treatment. In response to this high malaria challenge, a high degree of immunity is built up after early childhood. Under such conditions a moderate reduction in the number of infective bites may be insufficient to ensure that there are intervals during which all of a child's previous infections are eliminated before he or she acquires new ones. Furthermore, a prolonged reduction in the sporozoite challenge may reduce the level of immunity. Under such conditions of "saturating" malaria, there will be no simple relationship between the number of infective bites received (as expressed by the vectorial capacity) and prevalence of parasitemia. On the other hand, in those parts of the world where there is generally a long interval between recovery from one malarial infection and acquisition of the next one, a strong relationship may exist between reduction in vectorial capacity and reduction in prevalence of infection. These situations (as well as intermediate ones) are illustrated by Fig.1 which is based on data collected at Garki, Nigeria (Molineaux and Gramiccia 1980).

As shown, a 10-fold reduction of the vectorial capacity from D to C will probably not result in a detectable reduction in the parasitemia. But it may well cause a reduction in clinical malaria assuming that there is some relation between the number of sporozoites inoculated, parasite density and clinical malaria. This seems to correspond to the conditions in the villages in Burkina Faso (Carnevale et al. 1988, Procacci et al. 1988) and Tanzania (Curtis et al. 1989) in which impregnated netting has been tested. In The Gambia, Snow et al. (1988) observed parasite rates of 28.6% and 42.1% at the end of the transmission season among children in villages with permethrin- and placebo-treated nets, respectively. This corresponds approximately to the difference between B and C in Fig. 1, though Snow et al. (1988) concluded that the observed difference in parasite rates was not statistically significant. However, they found a highly significant difference in the number of febrile episodes with parasitemia during the transmission season in the villages with and without permethrin-treated nets.

On Hainan Island, China, (Li et al. 1988, Curtis et al. 1989) the treatment of nets in 2 successive years resulted in a decline in the end-of-season parasite rate from 8.5% (mostly *P. falciparum)* to 0.2% (only *P. vivax),* i.e., to a decline similar to the steep left hand part of the graph close to A in Fig. 1. There was a markedly lower incidence of malaria attacks in the 2 years with net treatment compared with the pretreat-

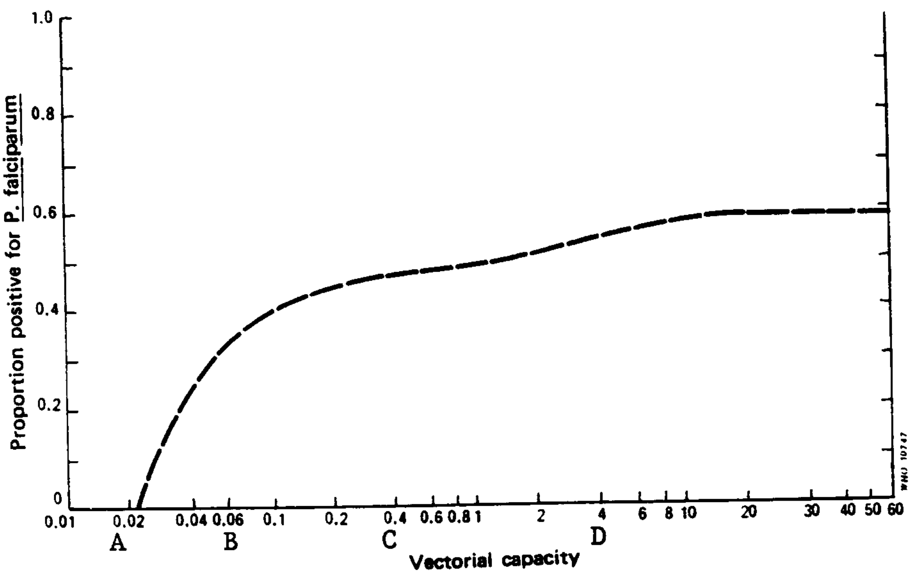

Fig. 1. Yearly average crude parasite rate as a function of yearly average vectorial capacity based on data from the project at Garki, Nigeria (after Molineaux and Gramiccia 1980).

ment years. Over these 3 years, there was a year-by-year increase in malaria incidence in the control area.

POSSIBLE IMPROVEMENTS IN THE EFFICACY OF IMPREGNATED NETTING

Most of the studies have emphasized the collection of entomological and epidemiological data in experimental hut studies and village scale trials. However, the chemical and physical factors which determine the insecticidal effect of an impregnated mosquito net have remained largely unexplored until recently. Understanding the relation between the mode of action and the chemical and physical components of impregnated mosquito nets will probably lead to substantial improvements. Some data which can be considered of practical importance are:

1) Hossain et al. (1986, 1989) demonstrated that on nets made from synthetic fiber, lower dosages of permethrin are required for a given mosquito kill than on cotton nets. Most of the insecticide may remain available for contact with the mosquito on the surface of the synthetic fibers, while part of the insecticide is lost in the crevices of rough cotton fibers. However, deltamethrin appears to be about equally effective on cotton and synthetic fibers (data of Hervy and Sales and Wu Neng cited in: Curtis et al. 1989).

2) The shape and size of the nets might influence the effect on the mosquito for several reasons. The smaller a net, the closer it will be to the human body and the more likely that the body will be in contact with the net, thus enabling mosquitoes to engorge. Larger nets have more surface area of impregnated material which might result in an increase of the tendency of the net to deter mosquitoes from entering houses or to repel them after they have done so.

3) The mesh size of untreated mosquito nets must be small enough to prevent mosquitoes from entering. This is not necessarily the case for insecticide treated nets. If the mesh size is less than the wing span, a mosquito will land on the net before trying to enter it (Itoh et al. 1986). A sufficiently high dosage of a pyrethroid prevents entry by mosquitoes (Kurihara et al. 1985, 1986; Hossain and Curtis, in press). Although wide mesh nets only offer protection in combination with an active insecticide, they provide better ventilation, an important advantage in hot climates. Moreover, they occupy less space when folded which make them more attractive to frequent travellers or nomadic people (Rozendaal 1989).

4) The pyrethroids used in the field trials mentioned above have been deltamethrin (at dosages of 15–25 mg/m^2) and permethrin (at dosages of 200–1,000 mg/m^2). In a recent experimental hut study (Miller, Lindsay and Armstrong, personal communication), several pyrethroids were compared with each other. Substantial differences in the effect on the mosquitoes were observed between the insecticides in their deterrency against house entry and killing effects. If only individual protection is required, one might choose to maximize the deterrent effect. But, if one aims for maximum reduction of disease transmission in a community by widespread use of nets, one should choose a treatment which maximizes mosquito killing.

5) The optimal dosage for impregnation still has to be determined for different netting materials and mosquito species. Lines et al. (1987) found no increase in efficacy against *Anopheles arabiensis* Patton in Tanzania when they raised the dosage for impregnating synthetic nets from 200 to 1,000 mg permethrin/m^2. By exposing hungry *An. gambiae* Giles in a small container to human skin protected with impregnated netting, Hossain and Curtis (1989) found that a dosage of 2.5 g permethrin/m^2 was needed to prevent feeding completely. However, in a study where a person sat under a net in a room and pressed his arm against it, a dosage of only 200 mg/m^2 was sufficient to prevent feeding by *An. gambiae* released in the room. This can be explained on the assumption that in the latter situation a mosquito would need more time to find the skin and thus may become irritated or incapacitated before locating it.

6) Nets can be very simply impregnated by soaking them in an aqueous emulsion of the pyrethroid and then allowing them to dry. Not much is known about the influence of different impregnation procedures on the effectiveness of the impregnated net. Because of chemical affinity between the polymer chain in synthetic fibers and the pyrethroid molecules, it may be that the pyrethroid will diffuse into the fiber instead of adhering on the outer surface. As was shown by Lindsay et al. (in press), increase in acidity and temperature of the impregnation can enhance absorption by the netting. Netting treated in this way appeared to retain insecticidal activity after washing slightly better than when it was treated in neutral pH and ambient temperature.

7) Spraying of the netting material with the insecticide is an alternative to soaking it (Loong et al. 1985, Rozendaal et al. 1989). This method offers the advantages of quick drying of the nets and the possibility of saving insecticide by only

spraying the lower parts of the nets which are closest to the human body (Rozendaal 1989). Spraying may be particularly appropriate where a net treatment program is to be carried out by personnel who are already trained in house spraying. The spraying of nets has been adopted in the largest operational net program so far—that in Sichuan Province, China (Curtis et al. 1989, Li et al. 1988).

RESIDUAL INSECTICIDAL ACTIVITY OF IMPREGNATED MOSQUITO NETS

Other factors which might affect residual activity are: 1) chemical degradation over time and by exposure to sunlight, 2) handling and folding for daytime storage and 3) washing.

Deposition of soot on a net in a smokey room does not have a serious effect on the availability of insecticide (Wilkes and Njunwa in: Curtis et al. 1989).

Several studies (Schreck et al. 1978, Snow et al. 1987a, Rozendaal et al. 1989, Lindsay et al. in press) show that washing can cause a severe decline in insecticidal activity depending on the method of washing. Without washing, the insecticidal activity started to decline after 4 months of use in an experimental hut (Darriet et al. 1984). Full effectiveness for periods of 12 months and more were found with unused nets hanging in a laboratory room (Loong et al. 1985, Li et al. 1987). The different bioassay studies are not readily comparable because of differences between impregnated nets, type and intensity of exposure and bioassay procedures. Bioassays with unrealistically long exposure periods of 30 min or 1 hour may not detect important reductions in insecticidal effect which are detected when exposure periods of a few minutes are used (Lines et al. 1987, Rozendaal et al. 1989).

SOCIOECONOMIC AND CULTURAL FACTORS AFFECTING VECTOR CONTROL WITH IMPREGNATED MOSQUITO NETS

As with residual house spraying which was successful in some areas and failed in others because of both technical and cultural factors, impregnated mosquito nets may not be appropriate everywhere. In areas with traditional usage of mosquito nets, introduction of impregnation is generally more likely to be acceptable to the community. In The Gambia where a high percentage of the population already use bed-nets (MacCormack and Snow 1986), it is planned to introduce impregnated mosquito nets on a large scale. In China, impregnation on a large scale of locally available bed-nets has already become an officially accepted malaria control method in several malarious provinces (Li et al. 1989, Curtis et al. 1989). However, in the interior of Suriname, where almost everybody uses mosquito nets, impregnation of these nets is unlikely to be adopted because of the local habit of washing the nets every week (Rozendaal et al. 1989).

Except among the poorest populations, the affordability of mosquito nets will in the first place depend on the perceived need to use a net. As was found by MacCormack et al. (1989) in The Gambia, the willingness to pay the local market price for mosquito nets increased markedly after inhabitants of several villages were given nets and thus learned to appreciate them.

Appreciation of mosquito nets will not only depend on reduction of mosquito bites and disease. In some trials it was demonstrated that impregnated nets suppressed the population of bedbugs, head lice and other nuisance arthropods, which was greatly valued by the users (e.g., Lindsay et al. 1989, Charlwood and Dagaro 1989).

Acceptance of mosquito net usage can also be enhanced by adapting the material, model and size to local preferences. The mosquito nets used in The Gambia and Suriname are not only used for protection against biting insects but also for privacy, protection against cold, dust, snakes, etc. For these purposes, opaque sheeting was preferred over transparent netting. In areas where people complain about a lack of ventilation under mosquito nets, impregnated wide mesh nets might be an acceptable alternative.

For organizations in charge of vector-borne disease control, it will be necessary to compare the cost-effectiveness of impregnated nets with other control methods such as residual house spraying. This comparison is difficult to make because of differences in the efficacy of the methods and social acceptability. Several vector control agencies have decided in favor of the use of impregnation of mosquito nets without having data proving its greater effectiveness than house spraying. Factors considered of high importance were low cost, lack of need for special equipment, fewer organizational and logistical problems, less insecticide needed and compatibility with local customs.

Net impregnation is a simple and innocuous operation, but it is important that pyrethroid concentrates are safely handled and that any surplus emulsion is not disposed of in streams where it could kill fish. Pit latrines are appropriate disposal sites, especially as they often constitute insect breeding places.

USE OF ALTERNATIVE MATERIALS FOR IMPREGNATION

Depending on the type of housing, human behavior, mosquito biting and resting behavior and climatological and economic factors, use of alternative materials for impregnation can be considered. Impregnated eave strips and curtains might offer a cheaper, more durable and, in some circumstances, more effective alternative to impregnated mosquito nets, especially for people living in small houses. Studies in Burkina Faso (Majori et al. 1987) showed that permethrin-treated strips in the eave openings and curtains over the door opening almost eliminated indoor biting by mosquitoes for a period of at least 3 months. No difference in parasite rates was observed, and there was a slight reduction in cases of fever with parasitemia in the season of high transmission. However, a significant reduction in such cases occurred during the season of low transmission (Procacci et al. 1988). In view of the problems with residual spraying of houses and impregnation of locally available mosquito nets in the interior of Suriname, a trial has been started with impregnated wide mesh gauze covering the eave openings and slits in the walls of the local houses.

For temporary shelters without walls it is possible to attach woven polypropylene sheeting impregnated or sprayed with a pyrethroid from floor to roof level to the poles which support the roof. Among gold miners in Brazil this method is greatly appreciated (W. D. Alecrim and P. A. Xavier, personal communication).

Where conventional mosquito netting is too expensive, impregnation of cheap local substitutes could be considered. Lines et al. (1988) and T. Wilkes and J. Myamba (personal communication) made curtains around a bed with fibers from polypropylene bags or with raw sisal and found that these curtains after impregnation with permethrin, pyrethrum or lambdacyhalothrin greatly reduced the number of mosquitoes which bite and survive. Raw sisal has recently been found to be dangerously inflammable (T. Wilkes, personal communication), but this objection does not apply to polypropylene.

DISCUSSION AND CONCLUSIONS

It can be concluded that impregnated mosquito nets are very effective in reducing exposure to biting mosquitoes and other pest and nuisance insects. Use of impregnated mosquito nets substantially reduces the number of infective mosquito bites received by a person in a malarious area. Whether this reduction in numbers of sporozoites inoculated results in a reduction of malaria prevalence and malaria morbidity will depend on a variety of local factors, among which are the level of endemicity of malaria, seasonal fluctuations in malaria and the immune status of the population. In areas or seasons with low transmission of malaria, impregnated bed-nets appeared to be effective in substantially reducing parasite rates (Li et al. 1988). In highly endemic areas, the reduction in the sporozoite inoculation rates may at best only result in a reduction of malaria morbidity by reducing the amount of superinfection. In these areas, impregnated mosquito nets would have to be supplemented by other malaria control methods if one hopes to reduce the prevalence of infection.

In view of the steep increase in numbers of people protected by impregnated mosquito nets in several countries in Asia and the Pacific areas, it can be concluded that this vector control method is particularly acceptable to the people in this region. Nets can be purchased wholesale for less than $3 (U.S.) each from several factories in Asia. In many countries in Africa the cost of nets is much higher and seems to be a major obstacle to adoption of this method by local communities and health organizations. Alternative materials, including impregnated screening and curtains, might offer a more appropriate alternative.

Locally appropriate delivery and management and operations of vector control with impregnated materials should also receive more attention. This method seems to lend itself very well for integration in primary health care programs because of its suitability for participation by communities. However, planning, coordination and delivery of the insecticide have so far been carried out by specialized agencies in all areas where impregnated bed-nets are being used. In China for example, some provincial vector control programs will supply concentrates of the insecticide to the villages at regular intervals and advise the inhabitants on how to impregnate their nets. Community participation remains limited to the usage and, sometimes, (re)impregnation of the nets. In some areas delivery of pretreated nets through the medical supplies system or through local commercial channels could be considered. Commercially pretreated nets might be of use to emergency aid organizations and to business travellers and tourists.

Comparison of the trials is difficult because of differences in study methods and the conditions in the study areas. In order to compare research data, future studies should provide extensive baseline data on the local epidemiology of malaria, mosquito densities, biting and resting behavior, human sleeping behavior, type and structure of houses and technical details of the impregnation of mosquito nets. To assess a community effect, the test and control populations should be far enough apart to have separate mosquito populations and preferably in pairs selected at random. Monitoring of malaria prevalence and morbidity should be by standardized methods. Differences between the results of some of the village scale trials can partly be accounted for by different methods for case detection, blood smear evaluation and assessment of malaria attacks and fever.

In view of the results in China (Li et al. 1988) and The Gambia (Snow et al. 1988), there is reason for optimism about the effectiveness of impregnation of nets in reducing the malaria problem. However, additional research is needed on such topics as:

1) Insecticide formulations which maximize the insecticidal effect and wash-fastness with due regard to economy and safety for the user.

2) Cost-effectiveness of the impregnation of nets compared to conventional housespraying (Li et al. 1988).

3) Evaluation of the threat of pyrethroid resistance and, if possible, forestalling it by the judicious use of pyrethroids or mixtures of pyrethroids with other classes of insecticide which are likely to minimize the rate of selection for resistance.

4) Reducing the excessive costs for the inhabitants of some developing countries of nets or other fabrics for impregnation.

5) Clarifying the effects of reducing the numbers of infective bites received by inhabitants of malaria holoendemic areas on morbidity and mortality from, and immunity to, malaria.

REFERENCES CITED

Carnevale, P., V. Robert, C. Boudin, J. M. Halna, L. Pazart, P. Gazin, A. Richard and J. Mouchet. 1988. La lutte contre le paludisme par des moustiques imprégnées de pyrethroides au Burkina Faso, Bull. Soc. Pathol. Exot. 81:832–842.

Charlwood, J. D. and H. Dagaro. 1989. Collateral effects of bednets impregnated with permethrin in controlling bedbugs (Cimicidae) in Papua New Guinea. Trans. R. Soc. Trop. Med. Hyg. 83:261.

Charlwood, J. D. and P. M. Graves. 1987. The effect of permethrin-impregnated bednets on a population of *Anopheles farauti* in coastal Papua New Guinea. Med. Vet. Entomol. 1:319–327.

Curtis, C. F., J. D. Lines, P. Carnevale, V. Robert, C. Boudin, J-M. Halna, L. Pazart, P. Gazin, A. Richard, J. Mouchet, P. M. Graves, J. D. Charlwood, M. I. Hossain, T. Kurihara, K. Ichimori, Z. Li, B. Lu, G. Majori, G. Sabatinelli, M. Coluzzi, K. J. Njunwa, T. J. Wilkes, R. W. Snow and S. W. Lindsay. 1989. Impregnated bednets and curtains against malaria mosquitoes, Ch. 2. *In*: Curtis, C. F. (ed.), Appropriate technology for vector control. C.R.C. Press, Boca Raton, FL.

Darriet, F., V. Robert, N. Tho Vien and P. Carnevale. 1984. Evaluation of the efficacy of permethrin impregnated intact and perforated mosquito nets against vectors of malaria. WHO/VBC/84.899 (mimeographed document).

Graves, P. M., B. J. Brabin, J. D. Charlwood, T. R. Burkot, J. A. Cattani, M. Ginny, J. Paino, F. D. Gibson and M. P. Alpers. 1987. Reduction in incidence and prevalence of *Plasmodium falciparum* in under-five-year-old children by permethrin impregnation of mosquito nets. Bull. W.H.O. 65:869–877.

Grothaus, R. H., H. K. Gouck, D. E. Weidhaas and S. C. Jackson. 1974. Wide-mesh netting, an improved method of protection against blood-feeding Diptera. Am. J. Trop. Med. Hyg. 23:533–537.

Grothaus, R. H., J. M. Hirst, H. K. Gouck and D. E. Weidhaas. 1972. Field tests with repellent-treated wide-mesh netting against mixed mosquito populations. J. Med. Entomol 9:149–152.

Hii, J., Y. S. Vun, K. F. Chin, R. Chua, S. Tambakau, E. S. Bibnisol, E. Fernandez, N. Singh and M. K. C. Chan. 1987. The influence of permethrin-impregnated bednets and mass drug administration on the incidence of *Plasmodium falciparum* malaria in children in Sabah, Malaysia. Med. Vet. Entomol. 1:397–407.

Hossain, M. I. and C. F. Curtis. Laboratory evaluation of deet and permethrin-impregnated wide-mesh netting against mosquitos. Entomol. Exp. Appl. (in press)

Hossain, M. I. and C. F. Curtis. 1989. Permethrin impregnated bednets—behavioral and killing effects on mosquitos. Med. Vet. Entomol. 3:367–376.

Hossain, M. I., C. F. Curtis and J. P. Heekin. 1989. Assays of permethrin-impregnated fabrics and bioassays with mosquitos. Bull. Entomol. Res. 79:299–308.

Hossain, M. I., C. F. Curtis, M. D. Smith and O. S. Ellis. 1986. Laboratory studies of permethrin impregnated nets and their effects on mosquitos. Trans. R. Soc. Trop. Med. Hyg. 80:842–843.

Itoh, T., G. Shinjo and T. Kurihara. 1986. Studies on wide-mesh netting impregnated with insecticides against *Culex* mosquitoes. J. Am. Mosq. Control Assoc. 2:503–506.

Kurihara, T., K. Fujita and T. Suzuki. 1985. Insecticide treatment of wide-mesh net curtain for vector control and the effect upon behavioural response of adult mosquitos. Jpn. J. Sanit. Zool. 36:25–31.

Kurihara, T., K. Kamimura and R. Arakawa. 1986. Phenothrin impregnation of wide-mesh net for protection from biting mosquitos. Jpn. J. Sanit. Zool. 37:261–262.

Li, Z., J. Xu, B. B. Li, T. Zhu and M. Li. 1987. Mosquito nets impregnated with deltamethrin against malaria vectors in China. WHO/VBC/ 87.939 (mimeographed document).

Li, Z., B. Lu and W. Xie, (eds.), 1988. The studies of bednets impregnated with deltamethrin for the control of vectors and malaria. Symposium, Guangdon Provincial Institute of Antiparasitic Diseases, Guangzhou, China.

Li, Z., M. Zhang, Y. Wu, B. Zhong, G. Lin and H. Huangi. 1989. Trial of deltamethrin impregnated bed-nets for the control of malaria transmitted by *Anopheles sinensis* and *Anopheles anthropophagus*. Am. J. Trop. Med. Hyg. 4:356–359.

Lindsay, S. W. and M. E. Gibson. 1988. Bednets revisited—old idea, new angle. Parasitology Today 10:270–272.

Lindsay, S. W., M. I. Hossain, S. Bennet and C. F. Curtis. A comparative study of 12 synthetic pyrethroid treatments impregnated into bednetting and their wash fastness. Pestic. Sci. (in press a)

Lindsay, S. W., R. W. Snow, J. R. M. Armstrong and B. M. Greenwood. 1989. Permethrin-impregnated bednets (mosquito nets) reduce nuisance arthropods in Gambian houses. Med. Vet. Entomol. 3:377–383.

Lines, J. D., J. Myamba and C. F. Curtis. 1987. Experimental hut trials of permethrin-impregnated mosquito nets and eave curtains against malaria vectors in Tanzania. Med. Vet. Entomol. 1:37–51.

Lines, J. D., E. Nicholson, C. F. Curtis, J. Myamba and T. Wilkes. 1988. Permethrin-treated sisal and polypropylene fibres as anti-mosquito bed-curtains in Tanzania. XIIth Int. Cong. Trop. Med. Malaria. Excerpta Medica, Int. Cong. Series 810:190. (abstract)

Loong, K. P., S. Naidu, E. S. Thevasagayam and W. H. Cheong. 1985. Evaluation of the effectiveness of permethrin and DDT-impregnated bednets against *Anopheles maculatus*. Southeast Asian J. Trop. Med. Pub. Health 4:554–559.

MacCormack, C. and R. W. Snow. 1986. Gambian cultural preferences in the use of insecticide treated bednets. J. Trop. Med. Hyg. 89:295–302.

MacCormack, C. P., R. W. Snow and B. M. Greenwood. 1989. Use of insecticide-impregnated bed-nets in Gambian primary health care: economic aspects. Bull. W.H.O. 67:209–214.

Majori, G., G. Sabatinelli and M. Coluzzi. 1987. Efficacy of permethrin impregnated curtains for malaria vector control. Med. Vet. Entomol. 1:185–192.

Molineaux, L. and G. Gramiccia. 1980. The Garki Project, World Health Organization, Geneva.

Procacci, P., L. Lamizana, S. Kumlien and G. Rotigliano. 1988. Longitudinal study on the impact of permethrin impregnated curtains on malaria morbidity in children. XIIth Int. Cong. Trop. Med. Malaria, Excerpta Medica, Int. Cong. Series 810:191. (abstract)

Rozendaal, J. A. 1989. Impregnated mosquito nets and curtains for self-protection and vector control. Trop. Dis. Bull. 7:1–41.

Rozendaal, J. A., J. Voorham, J. P. M. Van Hoof and B. F. J. Oostburg. 1989. Efficacy of local mosquito nets treated with permethrin in Suriname. Med. Vet. Entomol. 3:353–365.

Schreck, C. E., K. Posey and D. Smith. 1978. Durability of permethrin as a potential clothing treatment to protect against blood-feeding arthropods. J. Econ. Entomol. 71:397–400.

Snow, R. W., M. Jawara and C. F. Curtis. 1987a. Observations on *Anopheles gambiae* Giles s.l. during a trial of permethrin treated bednets in The Gambia. Bull. Entomol. Res. 77:279–286.

Snow, R. W., S. W. Lindsay, R. J. Hayes and B. M. Greenwood. 1988. Permethrin treated bednets (mosquito nets) prevent malaria in Gambian children. Trans. R. Soc. Trop. Med. Hyg. 82:838–842.

Snow, R. W., K. M. Rowan and B. M. Greenwood. 1987b. A trial of permethrin treated bednets in the prevention of malaria in Gambian children. Trans. R. Soc. Trop. Med. Hyg. 81:563–567.