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Insecticide impregnation can restore the efficiency of torn bed nets and reduce man-vector contact in malaria endemic areas

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Abstract

Three trials with torn bed nets impregnated with permethrin and deltamethrin were made under field conditions at the Soumousso Field Station and the Vallée du Kou rice-field area, both in Burkina Faso, and the Djoumouna fish pond area in the Congo Republic. Even a considerably torn correctly impregnated bed net could be an useful method for limiting human-anopheline contacts. But bed nets in poor condition, i.e. too little impregnated and too much torn, cannot protect the users against anopheline bites. Protection increases with insecticide concentration, but at a high dosage insecticide could have more a repellent than a killing effect. Therefore a balance has to be found for the optimum rate of insecticide treatment of bed nets to obtain a real reduction in malaria transmission and morbidity, in every epidemiological situation.

Introduction

The current spread of chloroquine-resistant *Plasmodium falciparum* strains in Africa south of the Sahara, after their appearance in south-east Asia and South America (DESFONTAINE, 1990), means that new vector control programmes are urgently needed and, due to the economic situation, they must be based on simple and inexpensive measures that encourage active community participation. Bed nets appear a suitable measure, particularly if their efficiency can be enhanced by impregnating them with a pyrethroid insecticide (ROZENDAAL, 1989).

A large number of surveys have recently demonstrated the efficiency of insecticide-treated bed nets in malaria control (CURTIS, 1990).

In the present paper we describe 3 trials to evaluate the efficiency limits of impregnated bed nets according to their condition (extent of torn surface) and insecticide concentration.

Material and Methods

Two surveys were carried out in Burkina Faso, the first in the World Health Organization Collaborative Centre field experimental station of Soumousso, the second in the Vallée du Kou rice paddy zone. The third survey was carried out in the République du Congo, near the Djoumouna fish farm.

Soumousso field station

This station is composed of 20 experimental huts equipped with window and verandah traps which prevent mosquitoes escaping once they have entered the houses (DARRIET *et al.*, 1984). Two sizes of bed nets were used: 10 m^2 and 13·6 m^2, and some were pierced with regular holes so that the torn surface represented 5% of the total surface of the bed nets (fifty 100 cm^2 holes in the small nets, 70 holes in the large ones).

The nets were impregnated with permethrin (EC 20) at 0·08 g/m^2, then placed in different experimental huts of the station. Assessment of efficacy was by hand catching, 3 times every morning, of the mosquitoes still in the houses: under the bed nets, free inside the house, and in the verandah traps.

In this report we have analysed only data obtained with torn bed nets, treated and untreated.

Vallée du Kou rice-field area

This area consists of 1000 hectares of rice paddy created 15 years ago, 25 km north of Bobo-Dioulasso (CARNEVALE & ROBERT, 1987). There is a large anopheline population, mainly *Anopheles gambiae* (Mopti cytotype), and a relatively low malaria transmission rate (ROBERT *et al.*, 1985). In VK 4, the village located in the centre of the rice paddy area, every inhabitant has a bed net, and their impregnation with deltamethrin (EC 25) at 25 mg/m^2 during a 3 years survey induced a 94% reduction of malaria transmission (ROBERT & CARNEVALE, 1991).

The aim of the present study was to observe the effect of impregnating torn bed nets on the number of bites on man inflicted by this wild *An. gambiae* population (DIOMANDÉ, 1987). 'Bait individuals' slept inside specially prepared bed nets which were fixed inside 4 similar houses in the village; these houses were side by side at the edge of the rice field. Cubic nets (11·25 m^2) with 80 holes in each (each hole measured=5·5×5·5 cm =30·25 cm^2, representing 2% of the entire bed net surface) were impregnated with deltamethrin (EC 25) at 25 mg/m^2 or 50 mg/m^2. The collections made under 2 of these treated nets (one intact, one torn) were compared to those made at the same time under 2 of the same type of untreated bed nets (normal or torn).

Three different trials were set up for one month each. In trial I, nets were treated with deltamethrin at 25 mg/m^2 and fixed for the night of the catching session only. In trial II, nets treated with 50 mg/m^2 were fixed for the night of the catching session only. In trial III, nets treated with 50 mg/m^2 were left inside the house for one month (the duration of the trial). In trials I and II the standard circular permutation system was used, to reduce the well known 'house effect'. We noticed the number of females caught while feeding and also those found dead (or nearly dead) on the floor around the net. Females still alive were kept in the insectarium to observe their delayed mortality rate.

Djoumouna fish farm area

This area has the highest known malaria inoculation rate in the world, with more than 1000 infected bites of *An. gambiae* per year per person (CARNEVALE, 1979).

For the trial we compared the efficiency of bed nets specially breached with holes cut to the extent of 2%, 1% and 0·5% of their surface area and treated with 3 different dosages of deltamethrin (25 mg/m^2, 12·5 mg/m^2 and 6·25 mg/m^2) (BITSINDOU *et al.*, 1990).

Three trials were conducted successively for one month each. Each trial involved one of the concentrations of deltamethrin, all 4 types of bed net (intact and with holes of differing extent) and 4 of the houses of the village; as in the Vallée du Kou trial, we used the circular permutation method.

Results and Discussion

First trial at Soumousso

The numbers of *An. gambiae* and *An. funestus* caught inside the houses furnished with torn bed nets, treated or untreated, are shown in Table 1.

The study confirmed what was observed in the whole

Table 1. Total number (and percentages) of *Anopheles gambiae* and *An. funestus* caught in Soumousso hut-traps furnished with torn bed nets untreated or treated with permethrin

Species	Nets	No. of mosquitoes caught[a] Ground	Bed nets	Verandah	Total
An. gambiae	Untreated	256 (52·3%)	85 (17·4%)	148 (30·3%)	489
An. gambiae	Treated	4 (2·2%)	2 (1·1%)	177 (96·7%)	183
An. funestus	Untreated	825 (57·7%)	218 (15·3%)	382 (26·8%)	1425
An. funestus	Treated	11 (2·4%)	0	454 (97·6%)	465

[a]Ground=mosquitoes found on the ground in the houses; Bed nets=mosquitoes found under the bed net; Verandah=mosquitoes trapped by verandah trap.

trial (DARRIET *et al.*, 1984), that even when torn the treated bed nets exerted a strong effect. If bed nets were not impregnated, most females of both *An. gambiae* and *An. funestus* remained inside the houses in the morning, and about 30% were collected in the verandah traps. In houses with treated torn bed nets this percentage increased from 30·3% to 96·7% for *An. gambiae* and from 26·8% to 97·6% for *An. funestus*. Almost no specimens remained inside impregnated bed nets.

The insecticidal treatment of torn bed nets also significantly reduced the rate of blood feeding by *An. gambiae*, which decreased from 98·9% (n=489) in houses with untreated torn bed nets to 80·8% (n=183) in houses with treated torn bed nets ($\chi^2=77{\cdot}9$; $P<10^{-6}$). A similar effect was noticed with *An. funestus*, with a significant drop from 97·7% (n=1425) to 84·5% (n=465) respectively in houses with untreated or treated torn bed nets ($\chi^2=115{\cdot}8$; $P<10^{-6}$).

In houses with untreated torn bed nets not a single female of either *An. gambiae* or *An. funestus* was found dead in the morning, while impregnation of the bed nets resulted in mortality rates of 17·8% for *An. gambiae* and 16·4% for *An. funestus*; this mortality was both immediate (43% for *An. gambiae* and 28% for *An. funestus*) and delayed (57% for *An. gambiae* and 72% for *An. funestus*).

Survey of the Vallée du Kou rice field

The total number of female *An. gambiae* caught in the different situations is shown in Table 2. It is clear that even with a large number of holes an impregnated net greatly reduced the number of bites received by the person under the net and this reduction was greater when the insecticide concentration was increased. The best protection was obtained when the impregnated bed net was left permanently inside the house, thus allowing the insecticide to act continually. With a torn net impregnated at 50 mg/m^2, left permanently in the house, the reduction in numbers of bites reached 56%.

The mortality rate of *An. gambiae* significantly increased in houses with deltamethrin-treated bed nets, from less than 30% in houses with untreated nets to more than 70% in houses with insecticide impregnated nets (Table 2). This effect was significantly reduced when the insecticide concentration was increased: it fell from 92·8% to 77·1 ($\chi^2=52{\cdot}8$; $P<10^{-6}$) when concentration was doubled from 25 to 50 mg/m^2 and dropped to 73·4% ($\chi^2=118{\cdot}2$; $P<10^{-8}$) when the nets were both heavily impregnated (50 mg/m^2) and left permanently inside the house.

This phenomenon could be considered a reflection of the irritant and repellent effect of the insecticide when used at high dosages, which then became more important than the lethal effect.

At the optimum dosage (25 mg/m^2) the feeding rate was considerably reduced (by 32%), due to a massive knock-down effect; at a higher dosage (50 mg/m^2) the feeding rate was reduced (by 44%) due to repellent and lethal effects. Constant use of highly impregnated bed nets reduced the feeding rate (by 56%), due to the irritant and repellent effects of the insecticide, which also resulted in a shorter contact time with the treated bed net and, therefore, a lower mortality rate.

The overall result was that even a considerably torn deltamethrin-impregnated bed net (at 25 or 50 mg/m^2) reduced by nearly 50% the contact between humans and *An. gambiae* in the Vallée du Kou.

Deltamethrin also resulted in delayed mortality; 46% of the mosquitoes which penetrated the torn bed nets treated at 25 mg/m^2 and were caught while feeding died within the following 24 h. The percentage mortality in trials II and III, with concentrations of 50 mg/m^2, were 16% and 5% respectively, confirming that mosquito contact with highly impregnated bed nets was greatly reduced as a result of the repellent effect.

Table 2. Night catches of female *Anopheles gambiae* in VK4, a village in the Vallée du Kou rice-field area (Burkina Faso)

Trial[a]	Bed net	Number	Bites/man/night	Difference	Dead	Mortality rate[b]
I	Untreated	1714	85·7		482	28·2%
	Treated	1172	58·6	−31·6%	1088	92·8%
II	Untreated	399	39·9		111	27·8%
	Treated	223	22·3	−44·1%	172	77·1%
III	Untreated	1155	64·2		325	28·1%
	Treated	507	28·2	−56·1%	372	73·4%

[a]Trial I: torn bed nets treated with deltamethrin at 25 mg/m^2, hung inside the house on the night of the catching session only. Trial II: torn bed nets treated with deltamethrin at 50 mg/m^2, hung inside the house on the night of the catching session only. Trial III: torn bed nets treated with deltamethrin at 50 mg/m^2, left permanently inside the house for one month.
[b]Numbers of dead mosquitoes/number caught.

Trial in the Djoumouna fish farm area

During the 3 months of this trial, 1949 females of *An. gambiae* were caught: 1343 within the torn untreated bed nets and 606 within the treated torn bed nets.

The feeding rate inside torn bed nets impregnated with deltamethrin at 25 mg/m^2 or 12·5 mg/m^2 was reduced by almost 60%, even if the bed nets had the largest holes (Table 3). At the very low concentration of 6·25 mg/m^2 the insecticide could still be effective as long as there were not too many holes. When the area of the holes exceeded 1%, a weakly impregnated bed net did not seem to be effective in preventing *An. gambiae* bites.

Table 3. Number of bites per man per night by *Anopheles gambiae* caught at Djoumouna fish farm (Congo Republic) under torn bed nets untreated or treated with different dosages of deltamethrin

	Dosage of insecticide on bednet (mg/m^2)								
	25			12·5			6·25		
Holes[a]	Untreated	Treated	Difference[b]	Untreated	Treated	Difference[b]	Untreated	Treated	Difference[b]
0·5%	30·7	11	−64·2%	32·7	14	−57·2%	17·2	10·7	−37·8%
1%	53·7	19·7	−63·3%	47·2	19·7	−58·3%	13·5	15·7	+16·3%
2%	84	27·5	−67·3%	39·7	15·2	−61·7%	16·7	14·7	−11·9%

[a]Holes=percentages of total surface of bed nets cut off by hand to form regularly shaped holes.
[b]Difference between biting rates.

This trial, made under actual field conditions, showed that, as expected, there is a limit beyond which a low dosage of insecticide on a largely torn bed net does not stop *An. gambiae* from feeding on man.

Nevertheless, it should be noted that all specimens caught while feeding inside treated bed nets, and then maintained in laboratory conditions, were dead within 24 h.

Conclusions

Bed nets in perfect condition can prevent 90% of bites (Snow *et al.*, 1988), but they are usually so damaged that mosquitoes are not stopped from taking a blood meal on the sleepers.

A lot of trials in different epidemiological situations (Curtis, 1990) have undoubtedly demonstrated the efficacy of bed nets impregnated with pyrethroid insecticides in reducing man-vector contact and malaria morbidity and even mortality.

The lower limit of protection which can be gained from such bed nets when used in field conditions, i.e. the minimum effective insecticide concentration and the maximum permissible area of holes, remains to be evaluated.

In Soumousso it appeared that permethrin (at 0·08 g/m^2) could have a greater repellent effect than a knock-down effect against the local populations of *An. gambiae* and *An. funestus*.

The rice field trial demonstrated that, as expected, when a normal bed net has a large number of holes (2% of surface area) there is a high *An. gambiae* attack rate, but if such a bed net is impregnated with deltamethrin at 25 or 50 mg/m^2 the attack rate could be reduced by about 50%. The greater the insecticide concentration, the greater the reduction, especially if bed nets are permanently left in the house. However, the high dosage had a repellent effect which could prevent mosquitoes from coming into contact with the impregnated bed net, resulting in a lower vector mortality rate.

The trial in the Djoumouna fish farm area showed that a considerably torn bed net impregnated with 25 mg/m^2 or even 12·5 mg/m^2 of deltamethrin (EC 25) could reduce the feeding rate of *An. gambiae*, but that 6·25 mg/m^2 was not sufficient to protect a sleeper under a bed net with a large number of holes.

All these studies showed that pyrethroid-treated bed nets could provide good protection against the main vectors of malaria in a sub-Saharan rural situation, as long as the insecticide concentration and the integrity of the bed net were adequate. Below a (so far undetermined) critical level they did not confer good protection, and to maintain their efficiency active community participation in taking care of, and regularly re-impregnating, the nets is essential.

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