Evaluation of a mass distribution programme for fine-mesh impregnated bednets against visceral leishmaniasis in eastern Sudan

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Summary   During an epidemic of visceral leishmaniasis (VL) in eastern Sudan, Médecins Sans Frontières distributed 357 000 insecticide-treated bednets (ITN) to 155 affected villages between May 1999 and March 2001. To estimate the protective effect of the ITN, we evaluated coverage and use of ITN, and analysed VL incidence by village from March 1996 to June 2002. We provided ITN to 94% of the individuals >5 years old. Two years later, 44% (95% CI 39–48%) of nets were reasonably intact. Because ITN were mainly used as protection against nuisance mosquitoes, bednet use during the VL transmission season ranged from <10% during the hot dry months to 55% during the beginning of the rainy season. ITN were put up from 9 to 11 p.m., leaving children unprotected during a significant period of sandfly-biting hours after sunset. Regression analysis of incidence data from 114 villages demonstrated a significant reduction of VL by village and month following ITN provision. The greatest effect was 17–20 months post-intervention, with VL cases reduced by 59% (95% CI: 25–78%). An estimated 1060 VL cases were prevented between June 1999 and January 2001, a mean protective effect of 27%. Although results need to be interpreted with caution, this analysis indicates a potentially strong reduction in VL incidence following a community distribution of ITN. The effectiveness of ITN depends on behavioural factors, which differ between communities.

keywords visceral leishmaniasis, insecticide-impregnated bednets, kala azar, Sudan

Introduction

The clinical and epidemiological characteristics of visceral leishmaniasis (VL, kala-azar) in Sudan have previously been published in detail (Zijlstra & el-Hassan 2001; Khalil et al. 2002; El-Safi et al. 2002; Elnaiem et al. 2003). Since the early 1900s, VL has been known to be endemic in the 'black cotton soil' region of southern Gedaref state in eastern Sudan, between the Blue Nile and the border with Ethiopia, especially along the Rahad and Atbara rivers (both tributaries to the Blue Nile; Figure 5). Incidence rates of 20–38 cases per 1000 person-years were reported in the village of Um-Salala along the Rahad River between 1991 and 1996 (Zijlstra et al. 1994; Khalil et al. 2002); and other villages in this region experienced VL incidence rates >50 cases per 1000 person-years in 1997 (Ritmeijer & Davidson 2003). The average annual incidence of reported VL cases in 190 villages in southern Gedaref state was 6.9 per 1000 person-years between November 1996 and

October 1999. During this period, high-incidence villages were significantly clustered around the two rivers (Rahad and Atbara) and in areas of low altitude and high rainfall (Elnaiem et al. 2003).

In 1996, Médecins Sans Frontières - Holland (MSF) established a VL treatment centre in the village of Um-el-Kher along the Rahad River. In October 1998, a second VL treatment centre was opened in Kassab, central Gedaref state, to provide treatment for patients along the Atbara River (Ritmeijer & Davidson 2003). The number of VL patients treated in the MSF treatment centres increased dramatically from 1233 in 1996 to 4618 in 1997, and 4432 in 1998 (Figure 1). As the epidemic unfolded, treatment capacity became overwhelmed, indicating the urgent need for the implementation of a VL prevention programme.

In January 1999, MSF started planning for a large-scale bednet distribution programme. The rationale for this policy was provided by, first, prior efficacy studies showing that insecticide-treated nets (ITN) provide complete
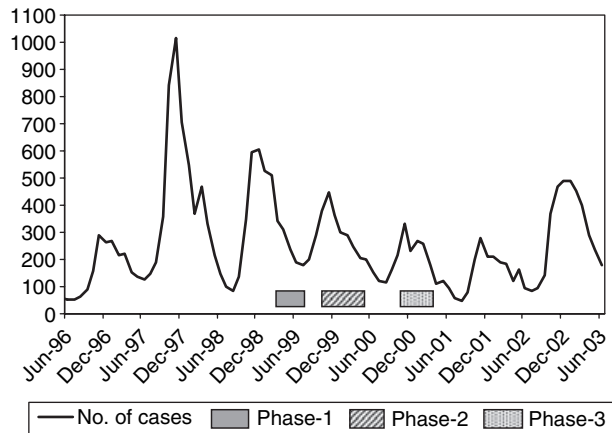
Figure 1 Total primary visceral leishmaniasis cases treated per month, and timing of different distribution phases, Gedaref state (1996–2002).

protection from bites of *Phlebotomus orientalis* (Elnaiem *et al.* 1999), the local vector (Elnaiem *et al.* 1998b; Hassan *et al.* 2004). Second, an ITN effectiveness trial in two villages along the Rahad River in 1995 had shown a reduction in the number of VL cases compared with the control village (Elnaiem 1996). Although the latter trial was small, a series of ITN trials in Syria, Afghanistan and Turkey (Tayeh *et al.* 1997; Reyburn *et al.* 2000; Alten *et al.* 2003) have all confirmed that ITN are effective in reducing the risk of leishmaniasis (in this case cutaneous leishmaniasis transmitted by *Phlebotomus sergenti*). Epidemiological studies in Nepal and Bangladesh have also reported that (untreated) bednet ownership was significantly associated with protection against VL (in this case transmitted by *Phlebotomus argentipes*) (Bern *et al.* 2000, 2005).

We considered that ITN were a better intervention than house spraying in eastern Sudan because it is unclear to what extent *P. orientalis* is endophilic, and because people often sleep outdoors during the hot dry season when sandfly infection rates are highest (Elnaiem *et al.* 1998b). Furthermore, ITN were practical for the local nomadic tribes. Finally, we considered that mass ITN distribution would offer protection against the concurrent malaria outbreak (Lengeler 2004), believed to be because of an increase in mosquito breeding sites as areas previously used for cotton cultivation became disused during the 1990s.

The MSF operation to provide ITN was an emergency intervention aiming to control the VL epidemic, despite the fact that available evidence for the efficacy of such intervention was limited, and the vector behaviour of *P. orientalis* was not entirely understood. On ethical

grounds, no attempt was made to leave a control group without nets, and the order with which villages were provided with nets was neither random nor matched. Despite these limitations, given that this MSF programme comprised one of the largest free distributions of nets carried out for any vector-borne disease, this paper describes the programme and attempts to evaluate its success. The evaluation is both operational, i.e. in terms of programme cost, net take-up, net usage patterns and net maintenance and also epidemiological, i.e. in terms of VL cases possibly prevented as the result of the programme.

Materials and methods

Study area and population

The ITN distribution programme was undertaken in southern Gedaref state. The climate is tropical continental with 600 mm of annual rainfall. There are three seasons per year: a dry winter from November to February with an average temperature of 27 °C, a hot dry summer from March to May with an average temperature of 32 °C and a 'cooler' rainy season from June to October with an average temperature of 26 °C. The population is composed of around 150 different ethnic groups, most of whom have only a recent history of settlement in the region, having migrated from western or southern Sudan and even from as far as West Africa. Most of the settlers are subsistence farmers. There is also a significant nomadic population, who live with herds of camels, cows and goats.

Southern Gedaref state consists of two provinces (Galabat and Atbara), both endemic for VL. These two provinces, with a population of ~445 000, incorporate 12 *mahalias* (local councils or districts), each comprising 15–25 villages each with 150 to 6000 inhabitants. Households consist of a nucleus family (average 5.1 individuals), living in a compound of three to five mud huts with grass-thatched roofs plus huts for livestock. People sleep inside during the rainy and winter season, moving their beds outside to the courtyard during the hot dry season. Young children usually sleep with the mother in a shared bed. Prior to the MSF programme, there was limited experience of bednets in the area. However, people use diesel as a repellent on the skin, and burn smoking fires at night to repel insects.

Bednet distribution programme

The target population was defined by studying patient registration data from the two VL treatment facilities (Um-el-Kher and Kassab) to determine the villages of origin. New maps to identify villages were developed using

survey maps from the 1940s, interviews and field visits. All villages are accessible by vehicle during the dry season and inaccessible during the rainy season when the black cotton soil turns to mud.

The aim of the project was to achieve 90% coverage of the population in eight of the most affected districts in southern Gedaref Sate (Figure 2). Excluded were Gala-Nahal, Al-Huri, Ban and Doka districts, where reported VL incidence rates were <1/1000/year.

A pilot distribution was carried out in October 1998 to test operational aspects of ITN distribution: 4227 insecticide-treated 156-mesh ITN were distributed in the village of Um-el-Kher, where the main VL treatment centre is located. The campaign was then implemented in three phases. The selection of villages for phase 1 was based on a combination of choosing villages with the highest numbers of registered VL patients, as well as opportunities to distribute in nearby villages in high-incidence districts. From May to July 1999, 44 995 ITNs were distributed in Bandegeo and Gureisha districts, and in the villages around the treatment centre in Kassab. Phase 2 was designed to continue targeting the remaining villages in Bandageo and Gureisha, and additionally to distribute nets to all villages in Hawata and Atbarawi districts, on the basis of their relatively high incidence reported from 1996 to 1998: 182 217 ITN were distributed from August 1999 to June 2000. Finally, phase 3 distributed ITN to all villages in the remaining target districts: 129 852 ITN were distributed between July 2000 and March 2001 in Al-Mugran, Basunda, Wadashair and Gureisha districts (Figure 2). In all the phases, care was taken to include nomadic groups settled during the dry season outside the villages.

In order to ensure ITN distribution to all individuals in a village, a three-step approach was developed with the approval and full cooperation of the popular committee in each village. The popular committee is a group of village representatives, amongst whom elected members serve on the local council of the district. The State Ministry of Health (SMoH) assisted by writing letters of introduction to the various local authorities, who were very co-operative. First, a village census was undertaken, numbering each house and registering all individuals in the household. Temporary nomadic camps that seasonally settled near the villages were also registered. After registration, one ITN was allocated per household member, except for children below 5 years who sleep with their mothers.

As the second step, health education was organized by the MSF teams, consisting of two expatriates and 20 local staff. Several one-day workshops were held in each village to train Village Health Volunteers (VHV), who were then responsible for communicating health messages to all villagers through home visits and workshops. VHV were selected by the popular committee, taking into account the following criteria: at least 50% should be women, and they should be respected or active in the community. A total of 1020 VHVs were trained, one per 500 people. The workshops were participatory, and included songs, role-plays and demonstrations of proper use of bednets, as well as discussions on people's beliefs about kala-azar. A few days after the training workshop, an evaluation workshop was held to detect and correct any misunderstanding or wrong health message.

The third step was the ITN distribution. The SMoH in Gedaref gave active support to the ITN distribution programme by transporting the bednets from Gedaref to the district, where they were stored. Each morning net was transported to the village in which distribution was to take place at a pre-determined distribution site. Heads of households were given the number of bednets as recorded during pre-registration. Members of the popular committee were present during bednet distribution to verify people's identity, and to maintain an orderly distribution. Beneficiaries were asked a contribution to the costs of a bednet.
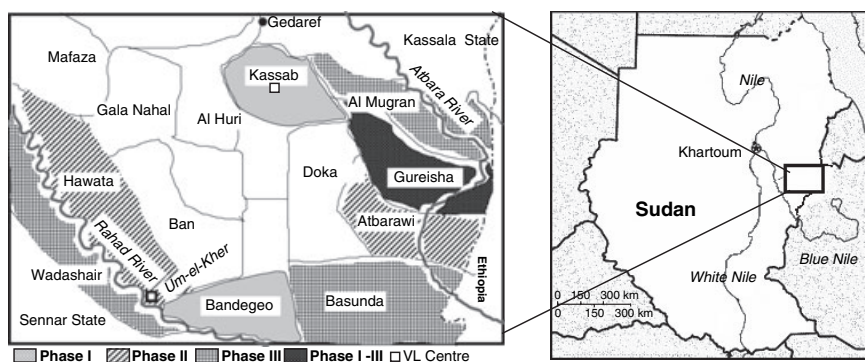

Figure 2 Southern Gedaref state by district and net distribution phase; visceral leishmaniasis treatment centres and rivers indicated.

During phase 1, the local council set this at 200 Sudan Dinars (US$0.80) per household, exempting households identified by the popular committee as too poor to pay. The collected fees were earmarked for health education activities in the area.

The first 22 000 ITN distributed (in the pilot study and part of phase 1) were made by SiamDutch Mosquito Netting Co., Bangkok, Thailand, in 156 mesh 75 denier, white polyester, deltamethrine-impregnated. The original plan was to organize regular re-impregnation rounds in cooperation with SMoH. However, only the bednets distributed in Um-el-Kher in October 1998 were re-impregnated in May 1999, with an 80% return rate. The re-impregnation was a collaborative action by MSF and SMoH. It took a team of 10 people 8 days to re-impregnate 3300 bednets, and 20 l of *K*-othrine (deltamethrine 25 g/l), which was donated by UNICEF.

From this experience, it was judged that a sustainable re-impregnation system was unrealistic owing to the absence of a suitable local infrastructure and logistics (e.g. very few functioning health clinics, lack of water), the inaccessibility and isolation of the villages during 5 months per year and the lack of funds and skilled staff for the SMoH to carry out the re-impregnation. Therefore, we switched bednet type to a fine meshed sandfly-proof ITN (SiamDutch green Jersey polyester netting; 300 holes/inch^2, double size, deltamethrine-impregnated). We considered that these should provide an effective physical barrier for sandflies after the insecticide lost its effect. In total, 353 516 of these nets were distributed in phases 1–3.

Operational evaluation of programme

Bednet coverage, usage patterns and maintenance. Bednet coverage was estimated by comparing bednets provided with the number of people identified in the MSF census to be allocated nets. Bednet usage patterns and maintenance were investigated by a community study undertaken from April to July 2001 in the villages of Afrosh Tobak, Bandegeo district, and Berber Fugera, Gureisha district. These villages had received nets in May 1999 and November 1999 respectively. Bednet use in households was observed during the main VL transmission season in April and May, when people slept outside. During 10 nights in each village, investigators walked around and observed bednet use. Focus group discussions were organized with separate groups of men and women. In each village, two male and two female groups were composed of 15 randomly selected adults (>15 years) per group. The discussion guide for the focus group discussions was semi-structured. Structured and open interviews were held with MSF staff members on the process of distribution and

health education, and with VL patients on bednet utilization and health-seeking behaviour. In the villages, informal talks were held with a variety of people to obtain more information on attitudes and utilization of bednets in the communities.

A second study in June 2001 used a structured questionnaire to survey 30 randomly selected households in each of the three villages: Afrosh Tobak (situated along the Rahad River), Berber Fugera (along the Atbara River) and Um Bileil (situated in central Gedaref state with no rivers close by). The villages had been provided with nets in May, November and July 1999, respectively. Interviews with the heads of household – including women if the husband was not present – provided quantitative and qualitative information on knowledge of VL and its transmission, bednet coverage, presence and condition, acceptability, reasons for bednet use and mode of use. Investigators counted the number of people sleeping under a net or not, and observed sleeping patterns and utilization of bednets, whilst walking around all three villages during the night.

Cost estimation. Total documented costs of the intervention were calculated, including the three distribution phases. Costs were split into cost of nets and additional costs (staff, transportation and storage).

Epidemiological evaluation of programme

In the principal analysis of the data (the 'main model'), we used a negative binomial regression clustered by village (giving robust standard errors) to test whether variation between villages in the number of VL cases reported each month was significantly associated with whether a village had been provided with ITN and for how long. The outcome measure was the number of cases in each month in each village. The effect of ITN was tested at 4-month intervals following provision of ITN to a village. The analysis was limited to the period when there were simultaneous treated and untreated villages (from May 1999 to March 2001). Hence, the intervention variable in the model comprised seven categories: no ITN; ITN provided to village from 1 to 4 months; ITN provided to village from 5 to 8 months; and so on up to ITN provided from 21 to 24 months. The analysis was adjusted by the underlying monthly variation in reported cases (i.e. by incorporating month as a categorical explanatory variable in the model), the underlying annual variation in reported cases (by incorporating year as a categorical explanatory variable in the model) and the log-transformed total number of cases reported in that village prior to the first intervention in the region, i.e. from March 1996 to May 1999 (incorporated as a continuous explanatory variable in

the final model). The analysis was then repeated – replacing the intervention categorical variable by a continuous variable to test the hypothesis that there was a trend in the changing effectiveness of ITN with time; a quadratic term (i.e. time-squared) was included in this model to test whether the trend was linear or non-linear. We tested the robustness of the conclusions by: (i) re-analysing the data after excluding phase-3 villages (which were less well-matched by pre-intervention incidence rates – Figure 3); and by (ii) carrying out a linear regression analysis on the logarithm-transformed monthly case data (+1).

An estimate of the number of VL cases possibly reduced because of the introduction of ITN was generated by comparing the total number of observed cases with the sum of the number of cases predicted (according to the coefficients derived in the 'main model') in each village and in each month in the absence of any ITN intervention (Figure 4). Further analyses were carried out to test for the possibility that some of this impact could have been because of epidemiological bias in the sequence in which villages were selected to be given bed nets.

First, we tested the hypothesis that at any point in the control campaign ITN were targeted to villages according to the total number of cases reported in a village during the previous year. A negative binomial analysis was carried out to test whether villages given ITN for the first time in a given month had a significantly higher number of reported VL cases in the previous 12 months as compared with the numbers of VL cases reported during the same period in those villages which were not then provided with ITN.

Second, we tested the hypothesis that targeting of ITN to villages was largely because of the number of cases in each village reported prior to the start of the campaign in May 1999. A negative binomial regression analysis was carried out to test whether villages tended to be provided with ITN
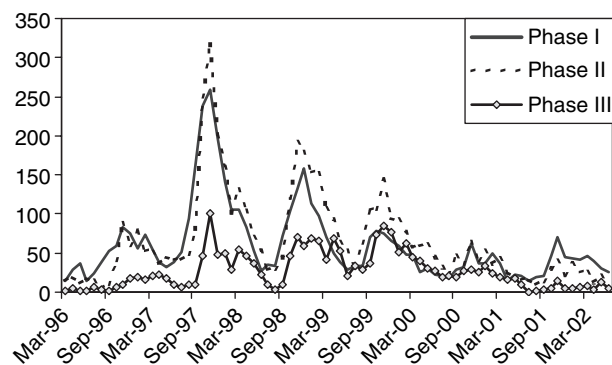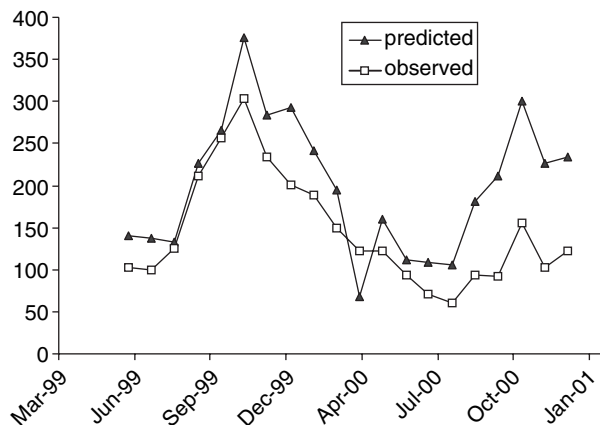

Figure 4 Predicted *vs.* observed cases of visceral leishmaniasis by month.

earlier during the control campaign if they had the greatest cumulative number of VL cases reported prior to the start of the campaign in May 1999 (Figure 5).

Results

Bednet distribution

A total of 357 064 ITN were distributed in 155 villages (Table 1). Based on the official 1998 and 1993 census data the population over 5 years of age in these villages was estimated at 230 000. However, this population figure was much lower than the number of 376 667 assessed during the demographic survey in the villages. During phase 2 of the distribution programme, 20 761 nets were re-distributed in Bandegeo to replace the 156 mesh ITN that had been distributed here during phase 1.

Figure 3 Total visceral leishmaniasis cases by month and by net distribution phase.

Table 1 Bednet target population and nets distributed in Gedaref state, 1999–2001

Local counsel	Beneficiaries registered	Bednets distributed	Coverage (%)
Bandegeo	33 067	42 761	129.3
Gureisha	57 216	51 472	90.0
Kassab	9927	9073	91.4
Hawata	87 996	83 712	95.1
Atbarawi	60 257	54 121	89.8
Almugran	35 872	32 196	89.8
Wadashair	38 529	33 369	86.6
Basunda	51 421	44 787	87.1
Others	2382	5573	234.0
Total	376 667	357 064	94.8

Community survey on bednet coverage and utilization

In the three villages of Afrosh Tobak, Berber Fugera and Um Bileil ITN had been distributed 26, 20 and 23 months, respectively prior to the survey. Data from the bednet distribution registration showed a bednet coverage in these villages of 93.6% of all individuals older than 5 years.

Of the 503 nets received by the 91 households interviewed, 328 (65.2%) were still present in the receiving family (Table 2). Of the missing nets, 77 (15.3%) were reported to be with family members elsewhere. Bednets are regarded as personal belonging, and are therefore taken during labour migration, travelling and family visits or to a new household in case of marriage. Thirty-seven nets (7.3%) were reportedly sold. This occurred only in the village of Berber Fugera, the poorest village. During difficult financial periods, a bednet is an asset of value to be sold. This was especially the case in families where the head of household was away from home to work as seasonal labourer on farms elsewhere, and the women stay behind with little resources. Bednets were sold near the Ethiopian border for 8000–10 000 SDD (US$ 3.10–3.90). Some families reported that they had to sell the bednet to pay for transportation costs to one of the VL treatment centres. Other reported reasons for missing nets were theft, burning or other severe damage.

Of the 328 bednets still present in the families, 115 (35.1%) were in good condition, i.e. without any damage; 104 (31.7%) were slightly damaged, i.e. had less than five small holes but would still have a protective effect; 109 (33.2%) were in bad condition, i.e. had more than five holes, one of which had a diameter of more than 5 cm. Results were identical in all the three villages. Main reported reasons for net damage were careless handling by children, taking the net out to the fields when farming, burning by sparks from cooking fires or damage by pointed objects. Children often slept under the most damaged nets. Although during the pre-distribution education demonstrations were given on how to repair nets, only 12 of the 213 nets with damages (5.6%) had been repaired. Two years after distribution, 43.7% (CI 39.4–48.2%) of all distributed nets were still present and reasonably intact.

People reported several methods for protection against diseases caused by insect bites. Bednets were most frequently mentioned. Before the ITN distribution programme, a limited tradition of using bednets existed in the region, using nets of locally available materials (cotton or polyester/cotton). The second preventive method mentioned was the use of oil (diesel, lamp oil) on the skin to repel insects. During the day or in the evenings 'bakhor', the strong smelling smoke of burning bark, was used. Other methods mentioned were good food and personal hygiene, environmental hygiene, putting oil on standing water, keeping the grass low around the compound, use of insecticides and spraying campaigns by the government.

Of the bednet users 54% (44/82) reported that protection against diseases was the main reason for using bednets, whereas 56% (46/82) mentioned 'having a good night sleep' as the main incentive, meaning a night without the disturbance of insect noise, bites, itching and mothers having to chase insects from young or sick children. Bednets were said to be used mostly against mosquitoes (93%), ants (55%) and only 29% mentioned sandflies as a source of nuisance. Apart from protection from nuisance insects during the rainy season, bednets also protect against snakes, scorpions and lizards that may fall from the roof onto the bed when people sleep indoors.

Bednets were most frequently used during the rainy season. During April and May, which are the hottest months of the dry season and the early part of the VL transmission season (Elnaiem *et al.* 1997; Lambert *et al.* 2002; Hassan *et al.* 2004), people slept outdoors and the reported and observed bednet use was <10% (Table 3). After the first rains in June, when the temperatures drop, and the number of insects (including mosquitoes and sandflies) increase, people shifted to sleeping indoors, and bednet use increased to 55%. Utilization data from the household survey corresponded with direct observations. After June, when the climate gets cooler, and the density of mosquito's further increases, all respondents said they used the bednets. Bednet use was similar in all the three villages.

People usually awoke between 5.00 and 7.00 hours, and went to bed between 18.00 and 23.00 hours. Only 4.3% of the study population went to bed before sunset, which

Table 2 Presence and condition of bednets in three villages, June 2001

Village	Local council	Population size	Interval since distribution (months)	Bednets received in sample	Bednets present	Bednets present and in good condition
Afrosh Tobak	Bandegeo	1150	26	136	117 (86.0%)	72 (52.9%)
Berber Fugera	Gureisha	5865	20	190	100 (52.6%)	69 (36.3%)
Um Bileil	Kassab	6000	23	177	111 (62.7%)	79 (44.6%)
Total				503	328 (65.2%)	220 (43.7%)

Table 3 Bednet use during different months in the visceral leishmaniasis transmission season in three villages

Month	Bednet use % (#)
June 2001	54.8 (46/84)
May 2001	10.7 (9/84)
April 2001	1.2 (1/84)

is the start of exposure risk to sandflies. If bednets were used, the first nets (for the children) were only put up after the evening meal, around 20:00–21:00 hours. Even when the young children ate and slept earlier, the mother did not yet prepare the bednets, as she was still busy with her household chores. Bednets were generally only prepared when the mother went to sleep. Depending on the day and the season, this was between 21:00 and 23:00 hours. While adults were relatively protected against insect bites during the unprotected hours after sunset by their clothing, which is long sleeved, the children often slept naked. If dressed the children still had bare arms and legs.

Without exception, all respondents were very enthusiastic about the impregnation of the nets. The dead insects found under or next to the nets were a strong motivation to use them. Two years after distribution, many people complained that nets had lost their insecticidal effect, and 43.6% of respondents were willing to pay for re-impregnation.

Two main disadvantages of bednets were mentioned. First, during the hot season it was considered too hot to sleep under the fine-mesh nets, which cut down ventilation. A second reason for refraining from bednet use was the daily routine to set up the nets before going to bed. This task is the responsibility of the mothers, and often they reported not having the energy at night, especially during the dry season, when people sleep outdoors, and nets had to be carried in and out of the house every day. During the rainy season, when people sleep indoors, the nets remain hanging above the beds, ready for use. Only occasionally the smell of the chemical, and rash caused by the chemical in the nets was reported.

Cost estimation

Total costs of the ITN distribution programme was calculated as US$ 2 286 195. Different cost items are specified in Table 4. The price of the impregnated Jersey net was US$5.10 per net. Including all additional costs for staff, transportation, administration and training, the average cost can thus be estimated as US$6.40 per net distributed.

Table 4 Costs of insecticide-treated bednet distribution

Budget item	US$ (%)
Nets	1 822 732 (79.7)
Staff	240 623 (10.5)
International staff (2)	125 411 (5.5)
National staff (~20)	115 212 (5.0)
Transportation and storage	146 986 (6.4)
Functioning and office costs	62 662 (2.7)
Training	13 193 (0.6)
Total costs	2 286 195 (100)

Epidemiological evaluation

After adjusting for log-transformed number of cases reported pre-May 1999, month, and year, we found that the number of cases reported by village and month was significantly reduced following ITN provision at all 4-month time points up to 20 months post-intervention (Table 5). The greatest effect was detected 17–20 months post-intervention, with the number of cases on average reduced by 59% (95% CI: 25–78%). Re-analysing the data with time of intervention treated as a continuous variable indicated a non-linear trend (*P* = 0.040), with the apparent protective effect significantly increasing with time (*P* = 0.010) up to 15.4 months after the ITN had been given out (when protection peaked at 54%). A significant non-linear trend (*P* = 0.034) was also detected when a linear regression analysis was carried out on log-transformed (monthly case number + 1) data, with protection increasing significantly up to 15.7 months after nets had been provided (*P* = 0.004).

As expected, the most endemic villages before the control campaign generally continued reporting the highest number of cases during the campaign (after adjusting for the other model variables). Specifically, the number of cases/village/month was significantly positively correlated

Table 5 Mean percentage reduction in the number of VL cases/village/month in villages which have had bed nets provided for different lengths of time, after adjusting for pre-intervention village incidence, month and year

Four-month time periods since introduction of bednets	Per cent reduction (95% confidence interval)	*P*-value
1–4 months	29.2 (4.5–47.6)	0.024
5–8 months	41.6 (10.5–61.8)	0.013
9–12 months	52.2 (19.3–71.6)	0.006
13–16 months	53.5 (19.6–73.0)	0.006
17–20 months	59.4 (24.6–78.1)	0.004
21–24 months	43.7 (−15.7–72.7)	0.118

with the log-transformed number of cases reported prior to May 1999 ($P < 0.001$). Cases per month after May 1999 increased 2.2-fold (95% CI 1.9–2.53) for every 2.7-fold increase in the pre-May 1999 case totals, indicating a roughly linear relationship.

Using the coefficients derived for this model (for intercept, year, month and log-transformed pre-intervention village sum of cases), a predicted number of cases in each village and each month was simulated in the absence of bednets from June 1999 to January 2001, i.e. the default value in the absence of an intervention. The total predicted was 3863, which compares of an observed number during that time of 2803. The implication is that the bednet intervention could have reduced the number of cases up to January 2001 by 1060, which means a calculated protective effect of 27.4%. The number of cases potentially reduced by the bednets after this date cannot be estimated as there were no remaining villages without bednets to make the comparison.

In order to test the robustness of the findings, we repeated the original analysis but excluding villages provided nets in phase 3, as these villages reported much lower incidence rates prior to May 1999 than villages in either phase 1 or phase 2 (Figure 3). While all the coefficients for the impact of bednets at various times post-intervention were again negative, none of the impacts were significant – in all cases $P > 0.2$. However, as before, the model coefficients became increasingly negative with time as the intervention with the maximum effect suggested between 17 and 20 months (coefficient = −0.420, 95% CI: −1.17−+0.833).

The reason for this lack of significant effect could be the result of a reduced sample size, or because the initial perceived effect was at least partly because of epidemiological bias, i.e. villages provided bednets latest had the least pre-intervention incidence. Therefore, we tested this in two ways. First, we tested the hypothesis that the probability that a village was selected for ITN in any given month was positively correlated with the number of cases reported in that village during the previous 12 months. No significant association was detected: $P = 0.730$. Second, we tested the hypothesis that targeting of villages for ITN provision was determined by the cumulative number of cases reported in villages prior to May 1999, i.e. before the start of the control campaign. In this case, a significant negative association was detected between the date when ITN were introduced and the total number of cases reported in that village between March 1996 and May 1999 ($P < 0.001$), with the delay in introducing ITN to a village increasing by 1 month for every 4.9% (95% CI: 1.0–8.6) drop in the total cases reported in that village prior to May 1999 (Figure 5).
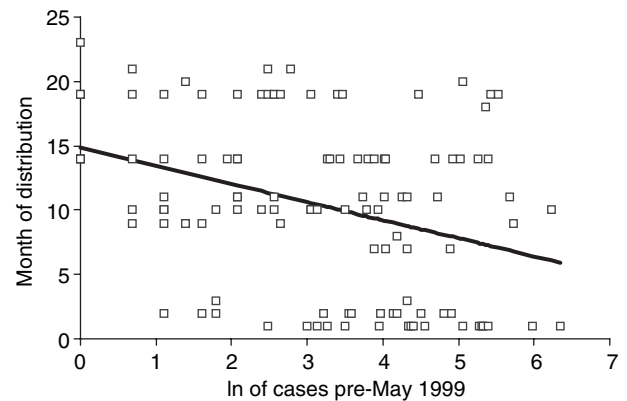

Figure 5 Months since April 1999 that nets were provided in a village, related to the total number of visceral leishmaniasis cases in that village pre-May 1999 (with fitted line).

Discussion

In this analysis of possibly the largest ever bednet mass-distribution programme undertaken, we estimate that VL cases were reduced by ~59% in the months 17–20 after distribution, and by ~27% overall. However, these figures must be treated with caution, as our estimates of apparent effectiveness may have been influenced by the non-random sequence of net allocation to villages (see next). The size of the apparent effect is especially surprising given the apparent low utilization levels of ITN reported during the programme. The explanation for this discrepancy could be an overestimation of the effect or an underestimation of the ITN utilization rates. Two alternative explanations could be that (i) widespread ITN utilization by villages led to a mass protective effect for the 'non-users'; or (ii) ITN utilization was more common amongst households at greater exposure of sandfly bites (and therefore those at greatest risk of leishmaniasis). Such a correlation has been demonstrated in a previous study of ITN utilization patterns in an endemic area of cutaneous leishmaniasis in Colombia (Pardo *et al.* 2006).

The utilization of bednets during April–May, believed to be the early part of the VL transmission season (Elnaiem *et al.* 1997; Lambert *et al.* 2002; Hassan *et al.* 2004), was low (<10%), and only increased during the later part of the VL transmission, after the onset of the rains. Even if people are provided with free nets, the decision of people whether to actually use the nets will be based on a balanced consideration of perceived needs, possible health gains, various disadvantages and convenience factors, which apparently results in sparse use of nets during the hot dry season, when there are few nuisance insects. Bednet use increases with the lower temperatures and increased

density of mosquitoes and other biting insects during the rainy season. Instead of focusing on promoting non-realistic and poorly acceptable messages of using bednets as soon as the sun sets, and during the hot season, emphasis might be better placed on alternative preventive methods, like wearing long sleeves (also for children) and the use of local repellents. Hence, behavioural studies are required before considering bednet distribution programmes. For example, in the VL-endemic regions in Upper Nile in southern Sudan, bednet acceptability and utilization during the hot dry season, and therefore the potential protective efficacy, might be higher. In Upper Nile state, people do not live in fenced compounds, as is the case in Gedaref state. The Dinka and Nuer population use traditional cotton untreated box-shelters (dumuria), which provide privacy as well as protection against insects, and ITN based on this design are being distributed in large numbers by Oxfam.

Locally produced impregnated ITN may be relatively ineffective, as they require regular re-impregnation. A sustainable re-impregnation system will be difficult to establish in the Eastern Sudan VL focus, owing to the size of the area concerned (>25 000 km^2), the fragile local infrastructure with very few functioning health centres and unpaved roads which do not allow vehicles to reach most areas for 4–5 months during the rainy season. Further restriction of movements during the dry season may be caused by insecurity because of the proximity of the Ethiopian border. There is also a lack of funds and skilled staff for SMoH to carry out the re-impregnation. In April 2000, the SMoH was not able to conduct re-impregnation of bednets distributed in phase 1 in three localities (Bandegeo, Gureisha border villages and Kassab-Um Bileil village) owing to financial and recourse constraints. Because re-impregnation would be essential to make 156-mesh bednets effective against sandflies, we switched to 300-mesh Jersey bednets, which are physically sandfly-proof, even after the insecticide has lost its efficacy (Schorscher 1999). More effective alternative solutions have become available in recent years: long-lasting treated nets such as PermaNet (Vestergaard Frandsen, Lausanne, Switzerland) (Graham *et al.* 2005), which have an insecticidal effect lasting at least 2–3 years without re-impregnation, and at the same time allowing a larger mesh (156 holes/inch^2), which provides more ventilation during the hot season.

When the condition of the bednets was assessed 20–26 months post-distribution, 43.7% of the nets were still present and sufficiently were intact to provide physical protection against sandflies. Residual chemical protection was not assessed, but will have been marginal at that stage (Curtis *et al.* 1996).

There are a number of reasons why our estimate of the epidemiological impact of ITN provision may be seriously inaccurate. First, incidence figures used in the epidemiological analysis were derived from MSF clinics, and therefore only represent reported VL cases, and not true incidence. This may have introduced a bias of underestimating true incidence, especially in the villages further away from the treatment centres, where physical and financial access to VL treatment is poorer. Nevertheless, the bias was consistent before and after the intervention as the number of cases after May 1999 in a village was directly correlated with the number before May 1999 in the same village. Second, increased awareness of VL after the health education activities may have resulted in improved health-seeking behaviour for VL, thus potentially biasing post-distribution incidence data. This may have underestimated the calculated protective effect of ITN. Third, it is clear that the order with which villages were provided with ITN during the control campaign was significantly biased towards those with more reported cases. Prioritization for ITN distribution was not decided by recent case data in those villages (i.e. during the previous 12 months) but was mainly based on overall cases per district pre-May 1999, because for operational reasons distribution was organized to cover district by district. Hence, a few villages with high numbers of cases pre-May 1999 did not receive bednets until the end of the programme (Figure 5). Given the non-random allocation of nets to villages, we cannot be confident how much, if any, of the estimated protective effect is real, as the estimate is contingent on the demonstrably false assumption that the overall temporal pattern of cases in each village would have been the same in the absence of bednets. It is also apparent that if nets had been used more commonly during the months of April and May, they might have had more impact.

The model coefficients indicate that the apparent effect of the bednets increased with time since the bednets were introduced, at least up to 20 months (Table 5). This trend was confirmed by an analysis, which treated time as the continuous variable. In this quadratic model, the protective effect appeared to peak at about 15 months. Possible reasons for a delay in the perceived effect of bednets include: (i) the month when nets were given may have been prior to the transmission season; (ii) the incubation period between infection and disease appearance; and (iii) a 'mass effect' increasing with time, as the prevalence of infectious humans drops (assuming humans are the principal reservoir host). The non-significance of the protective effect after 20 months post-distribution is probably a sample size issue, as there are fewer comparisons to make after 20 months. Alternatively, a drop-off in effect could reflect

the loss of insecticide effectiveness over time, the physical deterioration of the net and/or a drop-off in net usage.

The evaluation of the bednet campaign did not include an analysis of a potential reduction of malaria incidence because of the intervention. Contrary to kala-azar services, which were only provided in two treatment centres, and run by MSF, treatment of malaria is provided through many health facilities in the target area (public rural hospitals, health centres and health posts, as well as private clinics and markets), and reliable malaria incidence data were not available. The malaria situation in Gedaref state is characterized by unstable and seasonal transmission, which mainly occurs from September to November, and is entirely caused by *Plasmodium falciparum* (Giha *et al.* 2000). In the course of the rainy season (June-October), when mosquito density increases and temperatures drop, bednet usage becomes general. There is sufficient unambiguous evidence for the efficacy of ITN for prevention of malaria in Sub-Saharan Africa (Lengeler 2004) to assume that the bednet intervention has had a significant impact on the reduction of malaria transmission in eastern Sudan.

Recent studies have provided some further reasons to believe that the introduction of ITN might have played a role in the reduction in VL incidence observed in eastern Sudan between 1997 and 2002. There is good evidence that not only are high densities of *P. orientalis* frequently found inside houses in this region, but these domestic populations also have relatively high prevalence of *Lieshmania donovani* infections (Elnaiem & Osman 1998c; Lambert *et al.* 2002; Hassan *et al.* 2004). Furthermore, infection prevalence detected in domestic *P. orientalis* populations were lower in a village using ITN (0.5%) than in three villages without ITN (1.8–3.7%) (Hassan *et al.* 2004).

In conclusion, mass bednet distribution may potentially be an effective intervention against VL transmission by *P. orientalis* in Africa. Prospective community intervention studies, including a (randomized) control group, should give definite evidence. Future efforts should also be directed in optimizing the type of net and insecticide impregnation, and improving the utilization of nets during the *L. donovani* transmission season.

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Évaluation d'un programme de distribution en masse de moustiquaires imprégnées à mailles fines contre la leishmaniose viscérale dans l'est du Soudan

Pendant une épidémie de la leishmaniose viscérale (LV) dans le sud du Soudan, Médecins Sans Frontières a distribué 357 000 moustiquaires imprégnées d'insecticides (ITNs), à 155 villages affectés entre mai 1999 et mars 2001. Pour estimer l'effet protecteur des ITNs, nous avons évalué l'étendue de la couverture et l'utilisation des ITNs et avons analysé l'incidence de la LV par village de mars 1996 à juin 2002. Nous avons procuré des ITNs à 94% des individus de plus de 5 ans. Deux ans plus tard, 44% (IC95%: 39–48) des filets étaient raisonnablement intacts. Comme l'utilisation principale des ITNs est pour la protection contre les nuisances des moustiques, l'utilisation des moustiquaires durant la saison de transmission de la LV variait de moins de 10% durant les mois chauds et secs à 55% pendant le début de la saison des pluies. Les ITNs ont été utilisées à partir de 9 heures-11 heures du soir, laissant ainsi des enfants non protégées pendant une période importante des heures de piqûres par les phlébotomes i.e. dès après le coucher du soleil. L'analyse de régression des données d'incidence de 114 villages a démontré une réduction significative de la LV par village et suivant les mois de la distribution des ITNs. Le plus grand effet a été observé après 17–20 mois d'intervention, avec les cas de LV réduits de 59% (IC95%: 25–78). Il est estimé qu'environ 1060 cas de LV ont été évités entre juin 1999 et janvier 2001 ce qui représente un effet protecteur moyen de 27%. Bien que les résultats soient à interpréter avec prudence, cette analyse indique une réduction potentiellement forte de l'incidence de la LV à la suite d'une distribution d'ITNs dans la communauté. L'efficacité des ITNs dépend des facteurs comportementaux qui diffèrent selon les communautés.

mots clés leishmaniose viscérale, moustiquaires imprégnées d'insecticides, kala azar, Soudan

Evaluación de un programa de distribución masiva de mosquiteras impregnadas de malla fina frente a la leishmaniasis visceral en Sudan del Este

Durante un brote epidémico de leishmaniasis visceral (LV) en el este de Sudán, Médicos sin Fronteras distribuyó 357 000 mosquiteras impregnadas (MIs; malla de poliéster Jersey 300) en 155 poblados afectados, entre Mayo de 1999 y Marzo de 2001, con un coste de distribución de US$ 2,286,196, o US$ 6.40 por red, de los cuales un 80% correspondía al coste de la red. Con el fin de estimar el efecto protector de la red mosquitera, se evaluó la cobertura y el uso de MIs, y se analizó la incidencia de LV en cada poblado, entre Marzo 1996 y Junio 2002. Se distribuyeron MIs a un 94% de los individuos con menos de 5 años de edad. Dos años después, un 44% de las redes (95% CI 39–48%) estaban aún razonablemente intactas. Debido a que las redes se utilizaban sobretodo frente a mosquitos molestos, el uso de las mosquiteras durante la época de transmisión de la LV estaba entre un <10% durante los meses calientes y secos a un 55% durante el inicio de la época de lluvias. Las redes mosquiteras se colocaban entre las 9–11 p.m., dejando a los niños desprotegidos en el período que sigue a la puesta de sol, período crucial durante el cual pica la mosca de arena. Un análisis de regresión de los datos de incidencia de los 114 poblados, demostraba una reducción significativa de LV por poblado y mes después de la entrega de las redes mosquiteras. El mayor efecto fue de 17–20 meses después de la intervención, con una reducción del 59% (95% CI: 25–78%) de los casos de LV. Se ha estimado que se previnieron 1,060 casos de LV entre Junio 1999 y Enero 2001, con un efecto protector medio del 27%. Aunque los resultados han de interpretarse con cautela, este análisis indica que hay un potencial de reducción importante en la incidencia de LV después de la distribución comunitaria de Mis. La efectividad de las MIs depende de factores de comportamiento, que difieren entre comunidades.

palabras clave leishmaniasis visceral; mosquiteros impregnadas; kala azar, Sudan