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FACTORS AFFECTING USE OF PERMETHRIN-TREATED BED NETS DURING A RANDOMIZED CONTROLLED TRIAL IN WESTERN KENYA

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Abstract. Adherence with permethrin-treated bed net (ITN) use and their proper deployment was directly observed in 2,178 individuals (784 households) participating in a large-scale trial of ITNs on child mortality in western Kenya. The ITNs were distributed free of charge to ensure high coverage, resulting in a ratio of 1.46 persons per ITN. Approximately 30% of ITNs present were unused. The overall percentage adherence was 72.3%. The probability of adherence by individuals depended strongly on age (relative risk [RR] = 0.86, 95% confidence limit [CL] – 0.78–0.94), in which children less than five years of age were less likely to use ITNs than older individuals, and temperature, in which ITNs were more likely to be used in periods of cooler weather. A marginally significant diminution in adherence during the second year of the project was also observed (RR = 0.83, 95% CL = 0.68–1.01). Mosquito numbers, relative wealth, number of house occupants, and the educational level of the head of the household had no effect on adherence. In unstructured questioning of house residents, excessive heat was often cited as a reason for not deploying the child's ITN. The most important reason for non-adherence was disruption of sleeping arrangements, indicating that ITNs were not readily redeployed in the face of shifting sleeping patterns due to visitors, funerals, house construction, and other events. Challenges faced by health education programs to maximize adherence with ITN use are discussed.

INTRODUCTION

Multi-center trials have shown that insecticide (permethrin)-treated bed nets (ITNs) or curtains reduce all-cause childhood mortality by 14–33% in rural sub-Saharan Africa,[1–5] resulting in advocacy for the inclusion of ITNs, in particular, in a malaria control strategy for Africa.[6] While coverage of a population, defined as the proportion of the population possessing ITNs, is primarily influenced by the mechanism and economics of ITN distribution, adherence, defined as the proper deployment of ITNs, is influenced by a range of environmental and social factors. For example, in northern Ghana, ITNs were perceived to be of benefit for protection from seasonally abundant nuisance mosquitoes.[3,7,8] A decrease in use of ITNs was reported over the two-year trial period in Ghana, decreasing to 20% in the last dry season when temperatures were high and mosquito populations were low.[8] In Kilifi, Kenya, the proportion of ITNs in use decreased slightly during the project period, but decreased sharply after the project was completed.[9] The changing patterns of ITN use by season, and difficulties in encouraging community-sustainable approaches to ITN use were also described in Tanzania.[10,11] We describe here factors affecting directly observed adherence with ITN use in rural western Kenya in the context of a large-scale trial to assess the impact of ITNs on child morbidity and mortality where malaria transmission is both perennial and intense.[12] In this report, we test the hypotheses that age, temperature, rainfall, entomologic indices,[13] relative wealth, and educational status are associated with the probability that an individual will properly deploy his or her ITN. We associate these findings with results of unstructured interviews of study participants on reasons for non-adherence. Findings are discussed in relation to problems faced in the design and implementation of health education programs for this promising malaria control tool.

MATERIALS AND METHODS

Study population. The approximately 55,000 mainly ethnic Luo inhabitants of Asembo are highly dispersed, living in approximately 8,500 family compounds, each comprising an average of four houses surrounded by family-owned fields. The major occupation is subsistence farming and limited animal husbandry, but some individuals fish in Lake Victoria while others engage in local business. The most common type of house has a stick framework plastered with mud, a thatched roof, one door, and one or two windows. Eaves are open, allowing easy entrance and exit for mosquitoes. Though some houses have corrugated iron roofs, few of these have sealed eaves. Rainfall is bimodal with the long rainy season occurring from March through May and the short rainy season occurring in November and December. The predominant malaria vectors in the area are *Anopheles gambiae* and *An. funestus*. Malaria transmission in the area is intense and year round, with the average number of bites of potentially infective mosquitoes ranging from 60 to 300 per person per year.[14]

Baseline studies revealed few (<5%) houses using bed nets, with preference given to adults and visitors to prevent the biting of nuisance mosquitoes.[15] None of the bed nets in use before the project began were treated with insecticide. Children less than three years old sleep with the mother, although some <3s may be displaced to sleep with siblings on the arrival of a newborn to the family. Older children sleep in the kitchen and sitting room and teenagers may sleep in a house in their home compound or in surrounding compounds of relatives and friends.

Educational activities and ITN distribution. The ITN project, described in detail elsewhere,[16] incorporated extensive educational activities, including community wide meetings in every village, informal discussions with traditional birth attendants associated with the project, participatory educational theater, an art competition for a calendar design involving

schoolchildren that attracted hundreds of entries, and distribution of information sheets in Luo. Messages stressed through all media were 1) take ill children to health clinics promptly, 2) sleep under ITNs all year round every night and tuck in ITNs to keep mosquitoes from entering, 3) correct and consistent ITN use can reduce illness and death in young children, 4) wash ITNs only just before insecticide retreatment, and 5) keep ITNs in good condition by sewing up holes.

Upon ITN distribution in November and December 1996, participants were shown how to hang ITNs over either beds or floor mats, and were provided with twine and nails if needed. By the beginning of 1997, more than 17,000 permethrin-treated dark green bed nets (Siamdutch Mosquito Netting Co., Bangkok, Thailand) had been distributed in the 40 of 79 villages randomized to receive ITNs in Asembo. Our aim was to cover all previously counted and measured sleeping places (beds or mats) with an ITN of appropriate size. During 1998, an additional 4,600 ITNs were distributed for new immigrants and newborns. Bed nets were pre-impregnated with 0.5 g of permethrin/m^2 of netting and were re-treated to that target dose every 6–9 months. At each retreatment exercise, net and sewing materials were provided to residents whose ITNs were in need of repair. The ITNs were distributed to residents of the 39 control villages in the first quarter of 1999.

Data collection methods. Presence and use of ITNs were monitored through direct observation by study staff during early morning hours (4:30–6:00 AM). All communities had consented to participate in the process with the understanding that no house would be surveyed more than once; nonetheless, residents of survey houses were not aware that they would be monitored on a specific day. Monitoring was done quarterly during the two-year project; sampling was thus done on eight separate occasions, beginning in March 1997. We attempted to quantify ITN use in 100 intervention houses each quarter, or a total of 800 houses. Observations were actually recorded from 784 houses reflecting some under sampling and three refusals. Houses were sampled in clusters: the nine nearest neighbors of randomly selected index houses were sampled, yielding 10 samples per cluster. A similar method was used to select houses in control villages for entomologic monitoring. Prior to each survey, ITN distribution forms of selected houses were reviewed to ascertain the number of ITNs initially issued. At survey, study staff recorded 1) the number and age group of all people sleeping in the house, 2) the number of ITNs in use, 3) the number of ITNs present but not in use, 4) the number and age group of individuals either using or not using ITNs and 5) why household members, and specifically why children less than five years of age might fail to use their ITNs. This last question was asked whether or not children had been observed to use their ITNs. Any response was allowed; similar results were categorized together by the investigators.

Two hours after the initial visit, study staff revisited each household to ask more detailed questions about ITN use and travel in the previous month. Caregivers of children were interviewed if present; otherwise, an adult household resident was interviewed. At the same time, an entomologic survey was done in each house (including houses from control villages) to estimate the number of mosquitoes of different species found resting indoors. Details of entomologic methods are reported elsewhere.[13]

For most houses, baseline socioeconomic data were collected during the first year of the study to allow construction of an index of wealth, based upon observation of house construction, ownership of goods and livestock, and educational status of the head of the household and wives.[17] Daily rainfall and temperature were collected at four locations in Asembo throughout the project.[16]

Statistical methods. Data were entered by study staff and validated and cleaned by the investigators using SPSS release 9.0 software (SPSS, Inc., Chicago, IL). Analysis was performed using SAS release 8.1 (SAS Institute, Cary, NC) and SUDAAN (Research Triangle Institute, Research Triangle Park, NC) software packages. The following summary statistics were calculated: 1) coverage ratios, or number of people per project-issued ITN; 2) percentage of ITNs lost, as 1 – (number project-issued ITNs present/number ITNs issued) × 100; 3) percentage of ITNs present that were in use; and 4) percentage adherence, as number of persons under ITNs/total number persons in house for houses with ITNs present.

The percentage of people adhering to ITN use was calculated for two age groups: children < five years of age, and all other individuals ≥5 years of age. Seventy-six nets observed in houses that were not issued by the project were included in the calculation of the percentage of ITNs present that were in use and the percentage adherence, since these were treated with permethrin whenever project-issued ITNs in intervention villages were re-treated.

Entomologic indices were calculated based upon the mean densities of indoor resting *An. gambiae*, *An. funestus*, or *Culex quinquefasciatus* in control villages. Data for the two anopheline species were combined to produce an index of abundance for these two species combined. Anopheline or culicine densities in control villages were dichotomized into high or low categories with a cut-off value of 2 (the median value) per house. Use of numbers of mosquitoes collected from intervention houses was deemed inappropriate for this analysis, since adherence with ITN use markedly affects mosquito numbers.[13]

Socioeconomic variables included in the analysis were a wealth index, based upon house type and number and type of goods and livestock per house, and an education index, based upon completion of secondary school for the head of the household.

SUDAAN software for dichotomous comparisons allowed for correlation among observations taken from the same village. Similarly, for multiple Poisson regression modeling of factors affecting adherence, the GENMOD procedure in SAS assumed an exchangeable correlation structure for measures from the same village.

Ethical clearance. The bed net trial was reviewed and approved by the institutional review boards of the Kenya Medical Research Institute (Nairobi, Kenya) and the Centers for Disease Control and Prevention (Atlanta, GA). Informed consent was obtained from all caregivers after the study was explained in the local language.

RESULTS

Eight quarterly surveys were conducted between March 1997 and January 1999 consisting of visits to 784 houses (384

TABLE 1

Multivariate poisson regression analysis of percent change in proper use of insecticide-treated bed nets associated with year of project implementation, age of net user, temperature, number of culicine mosquitoes present in control village houses, number of anopheline mosquitoes present in control village houses, and wealth index*

Variable	% Change in adherence	RR (95% CL)	*P*	Risk group	Comparison group
Year	–17%	0.83 (0.68–1.01)	0.064	1998	1997
Age group	–14%	0.86 (0.78–0.94)	0.001	<5 years old	≥5 years old
Maximum temperature previous day	+31%	1.31 (1.01–1.69)	0.039	Lowest quartile	Highest quartile
Maximum temperature previous day	+29%	1.29 (0.98–1.70)	0.064	Medium-low quartile	Highest quartile
Maximum temperature previous day	+21%	1.21 (0.97–1.50)	0.088	Medium-high quartile	Highest quartile
Culicine density	–9%	0.91 (0.74–1.11)	0.35	≥2 per house	<2 per house
Anopheline density	+6%	1.06 (0.91–1.24)	0.45	≥2 per house	<2 per house
Wealth index	+8%	1.08 (0.97–1.21)	0.16	Top 25%	Bottom 75%

* Results for all variables in the final model are shown.

in year 1 and 400 in year 2) that contained 2,178 persons, of whom 446 were children less than five years of age or 11% of all children in the intervention villages in Asembo. The initial ratio of people to project-issued ITNs based upon records of ITNs issued was 1.46 (2,176 people to 1,488 ITNs). Coverage ratios in houses with children were higher than in houses without children (1.82 versus 1.19), reflecting the fact that children are more likely to share sleeping places, and thus ITNs, than adults. Of the 1,488 ITNs issued to the households we sampled, we found 1,372, or 92%, still in place. The percentage of ITNs present in houses that were in use was 73.5% in 1997 and 67.5% in 1998, but this difference was not statistically significant ($P = 0.10$).

For all surveys combined, the percentage of individuals found using an ITN was 72.3% (1,539 of 2,128). In univariate analysis, percentage adherence did not vary by year (75.3% in 1997 versus 69.4% in 1998; $P = 0.21$), but did vary significantly by age group (65.9% for those <5 years old versus 74.0% for those ≥5 years old; $P = 0.0062$).

The final regression model of factors affecting ITN use included year, age group, temperature, culicine abundance in control villages, anopheline abundance in control villages, and household wealth (Table 1). Various interaction terms were tested, but since these were not significant, they were dropped from the final model, which contains only main effects. Of these, the most clearly significant effect was age group, for which a 14.5% reduction in the probability of adherence was observed in children <5 years of age compared with individuals ≥5 years of age (relative risk [RR] = 0.86, $P = 0.001$). Relatively low temperatures were associated with increased adherence (RR = 1.31, $P = 0.039$), while the probability of adherence was marginally lower in year 2 of the project compared with year 1 (RR = 0.83, $P = 0.064$). Mosquito densities and relative wealth of the household did not have any effect on the probability of ITN use. This model does not include mother's secondary education as an effect since this variable was missing for 49% of households surveyed. In a model constructed using this reduced data set, and adjusted for all of the effects listed in Table 1, mother's education had no influence on the probability of adherence ($P = 0.31$).

Of 286 households queried about reasons for lack of ITN use by children, 186 (65%) replied that no problems were encountered. Remaining households gave a wide range of reasons for lack of children's adherence with ITN use. These have been grouped into four general categories in Table 2, along with details of specific responses. More than half of respondents cited a social or technical reason for lack of adherence, while 21% said that the children simply lacked ITNs.

DISCUSSION

The major outcome of this study, proper use of ITNs, was directly observed by study staff and modeled as a function of various environmental, social, and economic effects. A complementary, open-ended, qualitative approach was used to assess reasons for non-adherence with ITN use. Adherence is apparently simple: one must ensure that the corners of a

TABLE 2

Reasons stated by caregivers or household residents for lack of insecticide-treated bed net use by children less than five years old*

Environmental	21% (31)
Too hot (20)	
No mosquitoes (9)	
Too hot and no mosquitoes (2)	
Social	32% (48)
Disruption of sleeping arrangements (16)	
Child temporarily lacks caregiver (7)	
Child is a visitor, not a resident (7)	
Child's net used by another (5)	
Forgot to put up the net (4)	
Cannot use since child is sick (3)	
Funeral affected net use (2)	
Child is usually at another house (1)	
Visitor is using child's net (1)	
Mother or caregiver is away (1)	
Child fears ants will climb up net (1)	
Technical	21% (31)
No room to hang child's net (6)	
House reconstruction affects net use (5)	
Net is too small for bed or mat (3)	
Child rolls out of net (3)	
Roof is leaking, so cannot spread the net (3)	
Cannot hang the net properly (3)	
Child's net has been taken for mending (2)	
Difficult to spread net over mat (2)	
Returned home too late to put up the net (1)	
Net is too hard to put up and take down (1)	
Child's net is torn (1)	
Child's net was washed (1)	
Child is a new resident, so no net is available	21% (31)
Other reasons	5% (7)
Net is lost or misplaced (3)	
Unable to give reason (3)	
Net is stored (1)	
Total	100% (148)

* The number of responses of each type is indicated in parentheses.

rectangular ITN are attached to eaves and walls of one's room, lower the ITN before sleeping, and tuck the ITN under the bed or mat. The results of this study show that the probability these actions will be taken are dependent upon a range of variables, and that some variables that one would have predicted to affect ITN use do not, in fact, have an effect. The qualitative surveys done in conjunction with the direct observation of adherence support the results of the quantitative analysis while revealing the importance of unquantified social effects.

The study was conducted in a population with little experience with bed nets. The ITNs were given away to maximize coverage. We observed a ratio of 1.46 persons per ITN and found that approximately 30% of ITNs were unused, indicating that our efforts to saturate this population with ITNs were successful. Nonetheless, only 72% of individuals properly used their ITNs, when assessed by direct observation.

Both age and temperature affect the probability that an individual will deploy his or her ITN: people are less likely to use ITNs when it is hot, and older people are more likely to use ITNs than young children. While the effect of temperature is not surprising, it was disappointing to observe that young children, the age group most likely to have malaria, were less likely to adhere to ITN use than older people. During surveys conducted at the beginning of the project, residents expressed the view that ITN use is a higher priority for adults than for children.[15] For this reason, the project's educational efforts focused on the idea that since malaria is a more serious ailment in children than in older people, it is particularly important for young children to use ITNs. Despite these efforts, ITN use was nearly 15% lower in children than in older people.

Diverse reasons were given for lack of adherence with ITN use by children (Table 2). The leading single reason, "too hot," is supported by the quantitative analysis, but the second most common reason in the environmental category, "no mosquitoes," is not. While other studies[8,11] have indicated that lack of mosquitoes is a disincentive for ITN use, our results indicate that while some individuals may express such an opinion, objective behavioral change does not necessarily occur on a scale sufficiently wide to allow detection. However, given the year-round presence of at least some biting mosquitoes in Asembo, the fact that relatively low mosquito populations were not associated with reduced adherence does not necessarily imply that nuisance biting is not a motivating factor for ITN use in our population. It is worth noting that the pestiferous *Cx. quinquefasciatus* is 50% more abundant in our study area than anopheline malaria vectors.[13]

Of the social reasons given for non-adherence, disruption of sleeping arrangements was most commonly cited. In general, this response implies that normal sleeping arrangements were disrupted for one reason or another, and that therefore the ITN could not be deployed over the child. Many of the more specific reasons cited in the social category, "funeral affected net use," for example, are also instances where deployment of ITNs did not adequately track flexibility in sleeping arrangements, making this the most common reason overall for lack of adherence. Other social reasons relate to childcare and concepts of ownership that may affect the ability of people to effectively and promptly deploy ITNs while others, such as "forgot to put up net" may reflect low motivation. Low motivation may also be the underlying cause for some of the technical problems reported, such as "cannot hang the net properly, difficult to spread net over mat, returned home too late to put up the net," and "net is too hard to put up and take down," but some of the more common problems in this category reflect problems with space and house construction, such as "no room to hang child's net, house reconstruction affects net use," or "roof is leaking so cannot spread the net." One of the technical problems reported, "net is too small for bed or mat," is a consequence of the fact that some residents were given the wrong size net by the project, and some locally made single beds were larger than single ITNs.

Although one might expect that adherence with ITN use might increase over time as these various social and technical problems are worked out by individuals, in fact the trend was marginally ($P = 0.064$ in the multivariate analysis) towards decreasing adherence over time in both adults and in young children, as has been observed in other efficacy trials. That this occurred in spite of our educational campaign illustrates how difficult it is to impact on human behavior, and supports the idea that a careful and sustained health education program must accompany any ITN intervention. It is unlikely that this trend was due to unavailability of ITNs, given that 30% of ITNs present in the population were unused.

The degree to which lack of adherence with ITN use results in diminished protection against malaria is unknown, but results of a parallel analysis modeling numbers of blood fed indoor-resting mosquitoes shows that houses with ITNs deployed have significantly fewer fed mosquitoes than houses with no ITNs deployed.[13] This lends objective biologic support to the commonsense notion that deployed ITNs ought to provide more protection than those that are not. How then, does one design a health education program to maximize adherence? In our study, social and technical reasons stand out as barriers to ITN use. As visitors come and go, ITNs may or may not be moved to ensure coverage of children as sleeping arrangements change and the relative status of house occupants varies (a child may be allowed to use his or her ITN only when no adult is visiting). Further, some children sleep in sitting rooms or kitchens, making necessary daily removal and nightly re-hanging of ITNs. The ITNs may not be taken along when a child visits another compound, since the ITN may be viewed as a valued possession to safeguard rather than a tool to protect against malaria. Such problems may be directly addressed, once identified, using various techniques, such as role play, community discussion, or other methods, but there is no way to predict the effectiveness of each. Conversely, some of the difficulties associated with putting up and taking down ITNs might be ameliorated by distribution of easily removable and transferred screw-in eyelets, rather than nails, for hanging of ITNs.

As the impetus for implementation of ITNs for malaria control has grown, emphasis has rightly been on problems of cost and coverage. Problems related to adherence with ITN use may be implicitly dismissed by use of the adjective simple when describing ITN interventions. Our results illustrate the vital role that intelligently crafted health education programs must play to ensure that ITNs are used appropriately to achieve maximum efficacy.

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