DWELLING SPACE REPELLENTS: EFFECT UPON BEHAVIORAL RESPONSES OF MOSQUITOES IN ETHIOPIA [1, 2]

L. L. SHOLDT,[3] M. L. HOLLOWAY,[3] R. H. GROTHAUS [4] AND C. E. SCHRECK [5]

ABSTRACT. The interiors of Ethiopian mud and grass dwellings were treated with a space repellent, deet (N,N diethyl-*m*-toluamide), and the resultant effects on mosquito behavior assessed. Significant alterations in host finding, resting, and feeding behavior of anopheline and culicine mosquitoes were observed for 3 weeks after treatment. The potential use of "dwelling space repellents" in malaria control schemes is discussed.

INTRODUCTION. In recent years increased attention has been focused on the use of spatial action repellents in combination with wide-mesh bed-nets, net-jackets and other net items for protection against mosquitoes and other biting flies (reviewed by Grothaus, et al. 1974, 1976). Simpson and Wright (1967) proposed that area treatment with chemicals such as 2-ethyl-1, 3-hexanediol (Rutgers 612(R)) might substantially reduce mosquito annoyance and disease transmission by interfering with the insect's "attack programme." However, only a few field studies have been conducted on the use of space or area repellents other than on wide-mesh netting (Langford, et al. 1966; Means 1973; Gorham 1974). The need to investigate the use of repellents for area treatment has been stressed most recently by Wright (1975), based upon his studies of repellents and their effects on mosquito behavior.

Certain intradomestic insecticides with repellent properties such as DDT have been studied in this regard by several workers in Africa. Smith and Chadwick (1964), for instance, found that significant repellent action occurred against *Anopheles gambiae* Giles for 1 month after pyrethrum was applied to a native mud and grass hut in Tanzania. They suggested that a compound with effective residual-repellent action could break malaria transmission and discussed the conditions where this might occur. Similiar opinions have been expressed by other investigators including Ribbands (1947), Muirhead-Thomson (1960) and de Zulueta and Cullen (1963).

This study extends the concept of area repellency to native dwellings and records the effects on mosquito behavior under conditions found in Ethiopia.

The study was conducted in Gambela, a small, isolated administrative center of Illubabor Province in the Ethiopian southwestern lowlands. The study site was considered particularly suitable since the predominant tribe in the area is the Anuak who inhabit mud and thatched dwellings ("tukuls"). Gambela has never had an active malaria control campaign, and malaria is holoendemic, with transmission primarily by *A. funestus* Giles and A. *gambiae*. The ecology of the area and its anopheline populations has been discussed by Krafsur (1971).

MATERIALS AND METHODS. On the perimeter of an Anuak village, 4 circular tukuls, 2.6 m in diameter were constructed after the native manner with mud-lined walls and grass-thatched roofs. Openings included a door facing a swamp and mos-

[1] The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Navy Department or the naval service at large. This study was conducted under Naval Medical Research and Development Command, Work Unit No. MPNO3.12–5030.

[2] Mention of a pesticide or a proprietary product in this paper does not constitute a recommendation or an endorsement of the item by the USDA, or the U.S. Navy.

[3] U.S. Naval Medical Research Unit No. 5, APO New York 09319.

[4] U.S. Naval Medical Field Research Laboratory, Camp Lejeune, North Carolina 28542.

[5] Insects Affecting Man Research Laboratory, Agricultural Research Service, USDA, Gainesville, Florida 32604.

quito breeding area to the north and 2 small windows facing east and west, respectively. The door and west window openings were loosely covered with bamboo sticks woven in such a way that adequate space was left for the entrance and exit of mosquitoes. Window exit traps similar to those described by Hadaway (1950) were mounted in the east window openings. Paid Anuak volunteers occupied each tukul during the study.

Three of the tukuls were treated with deet (N,N diethyl-*m*-toluamide), a repellent of known spatial action (Grothaus, et al. 1974). An untreated hut (No. 4) served as control. Deet-ethanol solutions were applied to the walls and roof inside two tukuls (No. 2 and 3) at a rate of 54 and 108 gm/m^2 active ingredient, respectively, using a B & G$^{(R)}$ hand sprayer fitted with a Tee-jet$^{(R)}$ SS 8002 nozzle tip. The interior of tukul No. 1 was not sprayed but was covered with wide-mesh net panels pretreated with deet at a rate of 54 gm/m^2 to determine if the repellent might be significantly absorbed or otherwise lost on the mud and grass substrates. The panels were of polyester and cotton material as described for insect repellent jacket studies by Sholdt, et al. 1975.

The effectiveness of the treatment was determined by comparing the numbers of adult mosquitoes taken in collections from interior resting sites, night human-bait catches, and window exit traps. Resting site and exit trap collections were made for 3 days prior to treatment and, based on accessibility to the area from Addis Ababa, at post-treatment intervals of 1–4 days, 19–23 days and 50–51 days. Human-bait catches of 1.5 hours each were made as climatic conditions and adequate mosquito populations allowed. The study was terminated after 51 days due to an unexpected, early decline in mosquito populations.

Resting site collections were made in the early morning using "CDC Sweepers" (Hayes, *et al.* 1967) to aspirate all mosquitoes from the walls and roof. Night human-bait catches were conducted using pairs of collector-baits in each tukul and at an outside location 20 m from the test site. For each test in the study, the collectors and baits were rotated among the stations to overcome any differences in individual attractancy. The window traps were blocked off and checked each morning prior to the resting site collections. All mosquitoes collected were returned to the laboratory for identification and sorted as to the number of males, and the number of fed, unfed and gravid females.

RESULTS. The results of the resting site collections are shown in Table 1. On days 1 through 4 post-treatment, one mosquito was found resting in the 3 treated tukuls as compared to 163 in the control tukul. For days 19 through 23, 13 mosquitoes were collected from the 3 treated tukuls as compared to 318 in the control tukul. During the 4-week interval prior to the observations made on days 50 and 51, the control tukul unintentionally was unoccupied. This may explain why only 1 mosquito was taken from the control compared to 21 from the 3 treated tukuls. The majority of the mosquitoes collected were *A. funestus* and *gambiae* found resting primarily on the thatched roof just above the mud wall. Few were taken from the mud walls except near the window openings. The ratio of fed to unfed females was slightly higher for the treated tukuls as compared to the control. This finding is not significant because of the low numbers involved.

The results of the human-bait catches are shown in Table 2. During the first 4 days after treatment, no mosquitoes were collected from human baits inside the treated tukuls as compared to 47 in the control tukul. At 19 through 20 days after application, 7 collections were made from the treated tukuls and 3 in the control tukul. Observations were not made on days 50 and 51 due to insufficient mosquito pressure. Occupant complaints of mosquito annoyance were also noted throughout the study. Prior to treatment, the annoyance levels were considered relatively equal for all occupants. During the 3-week period after application, those sub-

Table 1. Average number of mosquitoes collected from resting sites inside dwellings treated with a residual space repellent.

Tukul No.	Substrate	Deet applied in gm/m²	Days Before Treatment	Days After Treatment		
			3–1	1–4	19–23	50–51
1	Netting	54	64.3	0.2	0	2.0
2	Mud and Grass	54	48.7	0	0.8	4.5
3	Mud and Grass	108	30.3	0	1.8	4.0
4	Control (Untreated)		65.0	40.8	63.6	0.5***
	Total anophelines* collected (Male & Female)		603	164	331	20
	Total culicines** collected (Females)		22	0	0	2

* Primarily *Anopheles funestus* and *A. gambiae*.
** Primarily *Mansonia africana* (Theobald) and *M. uniformis* (Theobald).
*** Tukul uninhabited between days 24–29.

jects in the treated tukuls reported being able to sleep undisturbed while the occupant in the control tukul continued to complain. Actually, the enthusiasm generated for the technique created some problems as other village members demanded that their dwellings receive similar treatment.

DISCUSSION. The number of females collected from the experimental tukuls was lower (female to male ratio=0.23) than in collections from village tukuls. Smith and Hocking (1962) suggest that human odor, resulting from long occupation, is important in attracting mosquitoes such as *A. gambiae* into native huts. Our freshly constructed tukuls therefore may not have been sufficiently competitive relative to the longer-inhabited dwellings nearby.

Window trap collections were disappointing since an average of only 1–2 females was taken in any 1 trap during the observations, and there were no discernible differences between any of the treatments. In studies with insecticides that

Table 2. Average number of female mosquitoes captured during human bait collections inside and outside dwellings treated with a residual space repellent.

Tukul No.	Substrate	Deet applied in gm/m²	Days Before Treatment	Days After Treatment		
			1	1–4	19–20	50–51
1	Netting	54	8.0	0	0.5	–
2	Mud and Grass	54	13.0	0	1.0	–
3	Mud and Grass	108	41.0	0	2.0	–
4	Control (Untreated)		14.0	11.8	1.5	–
	Total anophelines* captured inside		8	10	9	–
	Total culicines** captured inside		68	37	1	–
	Total mosquitoes from outside checks**		245	659	67	–

* Primarily *Anopheles coustani* Laveran, *A. funestus* and *A. wellcomei* Theobald.
** Primarily *Mansonia africana*, *M. uniformis*, and *Culex univittatus* (Theobald).
(–) Insufficient populations.

had repellent or irritant properties, Smith (1965) found that window traps showed lowered efficiency against *A. gambiae*. The females were deterred from resting and prematurely left the huts at night. Since there was no directional light source, they used openings other than the exit trap. This may in part explain our poor results.

The interpretation of the results was hampered by the limited number of observations permitted by inclement weather, transportation problems, and by an early decline in mosquito populations. We believe, however, that the data obtained demonstrate that for at least 3 weeks after application, deet altered the host finding, resting and feeding behavior of certain mosquito species when they entered or attempted to enter treated dwellings. While it was not possible to determine if there were differences between the treatment rates on mud and grass substrates, the treated netting material appears to have acted as a better repellent reservoir. The direct application of repellent to mud and grass substrates, however, seems feasible and needs further investigation.

The potential for dwelling space repellents is interesting to consider. Since World War II, some 25,000 compounds have been screened as insect repellents by various governmental agencies. Many of these are known to be considerably more effective than deet, but are cosmetically or toxicologically unacceptable for personal use. Such compounds might, however, prove acceptable for dwelling application. Compounds with high spatial action could possibly be used at low dosage rates or in limited areas such as strip treatments around doors, windows, other openings and primary resting sites.

The use of dwelling space repellents in malaria control campaigns might prove an effective ancillary tool to intradomestic residual pesticides, especially in areas where insecticide resistance has developed or a concern for environmental contamination must be considered. The technique might also be applicable in the case of endophagic but exophilic species such as *A. maculatus* Theobald and *A. nili* (Theobald) which feed inside but rest outdoors. After continued exposure to a repellent, anthropophilic feeding habits might be changed to zoophilic ones as suggested by Ribbands (1947) in his studies with Gammexane(R). Dwelling space repellents might prove useful for the protection of susceptible military, public health personnel and civilian volunteers who often work for limited periods in malarious areas. Particular attention could be directed towards the problem of nomadic tribes which live in structures that are poor substrates for insecticides and which move freely in and out of malaria control zones. A slow-release space repellent formulation similar to DDVP resin strips might prove of value under such conditions.

Future studies on dwelling space repellents should include more sophisticated experimental hut designs such as the verandah-trap huts described by Smith (1965) which more effectively measure changes in mosquito entrance, exit and feeding behavior. Also, investigations should be made to determine if space repellents can be used to interrupt disease transmission through the reduction of man-vector contacts. As discussed by Gabaldon (1949), the effectiveness of an insecticide should be measured in terms of malaria reduction and not deduced from entomological results alone.

ACKNOWLEDGMENTS. We gratefully acknowledge the generous advice and constructive criticisms of Dr. Ellicott McConnell, the field assistance of Negash Hanna and Sebahtu Hailu, and the continued support and encouragement of Captain C. K. Wallace, MC, USN, Commanding Officer of the U.S. Naval Medical Research Unit No. 5, during the period of this study.

References Cited

Gabaldon, A. 1949. The nation-wide campaign against malaria in Venezuela. Roy. Soc. Trop. Med. and Hyg. Trans. 43(2):113–160.

Gorham, J. R. 1974. Tests of mosquito repellents in Alaska. Mosquito News 34(4):409–415.

Grothaus, R. H., H. K. Gouck, D. E. Weidhaas and S. C. Jackson. 1974. Wide-wesh netting, an improved method of protection against blood-feeding Diptera. Amer. J. Trop. Med. Hyg. 23(3):533–537.

Grothaus, R. H., J. R. Haskins, C. E. Schreck and H. K. Gouck. 1976. Insect repellent jacket: Status, value and potential. Mosquito News 36(1):11–18.

Hadaway, A. B. 1950. Observations on mosquito behaviour in native huts. Bull. Ent. Res. 41:63–78.

Hayes, R. O., G. E. Kitaguchi, and R. M. Mann. 1967. The "CDC Sweeper" a six-volt mechanical aspirator for collecting adult mosquitoes. Mosquito News 27(3):359–363.

Krafsur, E. S. 1971. Malaria transmission in Gambela, Illubabor Province. Ethiop. Med. J. 9:75–94.

Langford, G. S., S. R. Joseph and R. Berry. 1966. Some observations on mosquito repellents. Mosquito News 26(3):399–404.

Means, R. G. 1973. Preliminary evaluation of the effectiveness of Mosquito Beater®, a granular repellent, against mosquitoes and blackflies. Mosquito News 33(4):542–544.

Muirhead-Thomson, R. C. 1960. The significance of irritability, behaviouristic avoidance and allied phenomena in malaria eradication. WHO Bull. 22:721–734.

Ribbands, C. R. 1947. The use of residual films of DDT and Gammexane in malaria control. Bull. Ent. Res. 37:567–592.

Sholdt, L. L., R. H. Grothaus, C. E. Schreck and H. K. Gouck. 1975. Field studies using repellent-treated wide-mesh net jackets against *Glossina morsitans* in Ethiopia. East Afr. Med. J. 52(5):277–283.

Simpson, J. E. and R. H. Wright. 1967. Area treatment to combat mosquitoes. Nature (Lond.) 214:113–114.

Smith, A. 1965. A verandah-trap hut for studying the house-frequenting habits of mosquitoes and for assessing insecticides. I.—A description of the verandah-trap hut and of studies on the egress of *Anopheles gambiae* Giles and *Mansonia uniformis* (Theo.) from an untreated hut. Bull. Entomol. Res. 56:161–167.

Smith, A. and P. R. Chadwick. 1964. A reassessment of pyrethrum against *Anopheles gambiae* with particular reference to its action as a residual repellent. East Afr. Med. J. 41(4): 137–141.

Smith, A. and K. S. Hocking. 1962. Assessment of the residual toxicity to *Anopheles gambiae* of the organophosphorus insecticides malathion and Baytex. WHO Bull. 27:231–238.

Wright, R. H. 1975. Why mosquito repellents repel. Sci. Amer. 233(1):104–111.

Zulueta, J. de and J. R. Cullen. 1963. Deterrent effect of insecticides on malaria vectors. Nature (London.) 200:860–861.