ORIGINAL RESEARCH

Passive Prophylaxis With Permethrin-Treated Tents Reduces Mosquito Bites Among North American Summer Campers

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Objective.—Over 2 million adolescents participate in summer-camp experiences, placing themselves at risk for mosquito-borne illness. Insect repellent is recommended but often not used. It is unknown whether permethrin treatment of a location, such as a campsite, provides passive prophylaxis reducing mosquito bites among all persons in the immediate vicinity.

Methods.—This randomized, double-blind controlled trial used 0.4% permethrin (2.5% permethrin diluted by 7 parts water) sprayed once onto the external surface of canvas tents at a Boy Scout summer camp. During a 9-week period, subjects ($n = 545$) completed nightly mosquito-bite and -landing counts for 5 minutes at dusk and recorded insect-repellent use within 2 hours of counting. Weekly mosquito sampling with CO₂-baited Centers for Disease Control and Prevention traps occurred at study campsites. The primary outcome measure was the number of mosquito bites per 5 minutes.

Results.—A total of 1614 person nights averaged 5.1 ± 7.2 ($\pm$ SD) mosquito bites per 5 minutes. The permethrin-treated campsites had decreased mosquito landings and bites (relative risk reduction [RRR] 44%; 95% CI 34% to 55%; $P < .001$) compared with controls. Insect repellent was used only 32% of nights, decreasing bites by 36% (RRR 36%; 95% CI 25% to 47%; $P < .001$). Permethrin was superior to insect repellent alone (RRR 20%; 95% CI 4% to 37%; $P = .01$).

Conclusions.—Permethrin treatment of tents is an effective, inexpensive public health measure to reduce mosquito bites. Permethrin is effective among all individuals in a camping setting and was more effective than topical insect repellent alone, which, although recommended, was inconsistently used.

Key words: mosquito, permethrin, camping, randomized controlled trial, West Nile virus, DEET

Introduction

Mosquitoes transmit diseases worldwide to more than 700 million persons annually and account for 1 in 5 childhood deaths in Africa.^{1,2} Mosquitoes will kill 1 in 17 persons currently alive on the planet through diseases such as malaria, dengue, and mosquito-borne encephalitis.^{1,3} Mosquitoes traditionally have been a concern of the developing world, yet the arrival of West Nile virus in North America has renewed public attention and concern toward these insects. Indeed, the cost of medical care for mosquito-borne illness is rapidly rising in the

United States. In 2002, the direct medical cost for care associated with West Nile virus is estimated at more than \$140 million, with the average hospitalization costing \$23 900.⁴

Many organizations for adolescents participate in summer-camp experiences, immersing themselves in the North American outdoors. Chief among these organizations is the Boy Scouts of America. In 2001, over 2 million youth members of the Boy Scouts of America participated in summer camp, placing themselves at increased risk for zoonotic diseases.⁵ With the rising concern over mosquito-borne arbovirus encephalitis, such as La Crosse or West Nile virus, avoidance of mosquitoes is the best protection against disease.

Many commercially available mosquito repellents contain *N,N*-diethyl-*m*-toluamide, now called *N,N*-dieth-

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yl-3-methylbenzamide (DEET). DEET is an effective topical mosquito repellent generally providing 1.5 to 5 hours of protection, depending on formulation and concentration.⁶ However, even when a recommendation for insect-repellent use is given, daily use often does not occur, much less the frequent application needed for protection.^{7,8} In a study of Australian soldiers in East Timor, only 19% used DEET daily, and DEET usage did not correlate with malaria; however, permethrin-treated bed nets were protective against malaria.⁷

Permethrin, a semisynthetic insecticide similar to pyrethrum, is naturally derived from the *Chrysanthemum* flower. It has been shown to reduce the incidence of mosquito bites for weeks after a single application to clothing, even with routine laundering.^{9–11} Permethrin acts not as a repellent but as an insecticide through prolonged depolarization of the insects' presynaptic-nerve sodium channels. When mosquitoes approach prey and land on treated surfaces, such as clothing or tents, the permethrin kills them. The result is a decreased mosquito population, not just 1 mosquito temporarily repelled. The combination of permethrin on clothing and DEET on skin results in a formidable barrier providing 99.9% protection against mosquito bites, even under conditions in which unprotected subjects received an average of 1188 bites per hour.¹² Two previous pilot studies have examined permethrin-treated tents. Eight volunteers sleeping inside a permethrin-treated tent had a 84% to 94% reduction of mosquito bites.¹³ Even those sleeping outside a treated tent had a 43% to 82% reduction of mosquito bites.¹³ The duration of effectiveness of tent treatment is at least 6 to 12 months.^{14,15}

In Minnesota during 2002, sampling revealed 90.5% of mosquitoes are *Aedes* and *Ochlerotatus* varieties.¹⁶ They are active predominantly dusk through dawn but mostly at dusk, and campers are typically near but not necessarily inside their tents.

The goal of this project was to determine whether permethrin treatment of tents can be used as an adjunct method to reduce the number of mosquito bites acquired in wilderness locales. An inexpensive, single application of permethrin would improve compliance and decrease dependence on frequent use of topical repellents. Permethrin treatment of tents may be a viable public health adjunct to reduce mosquito burdens and reduce zoonoses acquired in camping environments. This study investigates the effect of permethrin treatment of tents as passive prophylaxis against mosquitoes.

Methods

This double-blind, randomized controlled trial was conducted at Tomahawk Scout Reservation on Long Lake

in northwestern Wisconsin, which serves approximately 5500 scouts each summer.¹⁷ A lakefront subcamp with 9 campsites each with 12 tents erected for the 9-week summer camping season was chosen for study from June 14 through August 20, 2003 (Figure 1).

Campsites were randomized in a linear Latin square design: campsites 1 and 2 (treatment); 3, 4, and 5 (control); 6 and 7 (treatment); and 8 and 9 (control). On June 14, 2003, treatment campsites received 0.4% permethrin sprayed for 1 minute to the external surfaces of canvas-wall tents (surface area = 22.2 m²) mounted on wooden platforms. This study used 2.5% permethrin (PBI Gordon, Kansas City, MO) diluted by 7 parts water (cost \$10.95) and was sprayed by an independent individual 1 time only with a hand-pump stainless steel sprayer (Root-Lowell Flomaster Model 112, Lowell, MI) to treatment tents.¹⁸ The average calculated concentration achieved was 197 mg·m⁻². The distance to the nearest water source, a lake, was similar for all campsites in this study (50 ± 5 m). Wetlands (ie, mosquito breeding areas) were near campsite 1 and between campsites 5 and 6. Prevailing winds were from the west, nearest campsite 1. The subjects were blinded as to whether their tent was treated. Permethrin does not have an odor and was applied before the scouts' arrival in camp.

Individual scouts spent 1 week in camp. Mosquito-biting data were collected each week on the first 4 nights of camp at dusk, the most active period of mosquito activity. Subjects were asked to record during a 5-minute period at dusk the number of mosquito landings or bites incurred. At dusk, scouts would be in their campsite but not inside their tents. Inquiry also assessed any personal insect-repellent use 2 hours before dusk. Two hours was chosen as the time cutoff because the previous opportunity to potentially apply insect repellent would have been more about 8 hours earlier. This would have been generally beyond DEET's effective duration.⁶ Data were collected on self-reported surveys distributed weekly to each scout-troop leader. These adult leaders received instruction from an onsite research coordinator, who was blinded to the treatment group and was responsible for data collection and weekly mosquito sampling. The study lasted 9 weeks.

Mosquito sampling occurred simultaneously at 4 locations (2 controls and 2 treatments). These locations were between campsites 1 and 2 (treatment); 3, 4, and 5 (control); 6 and 7 (treatment); and 8 and 9 (control) (Figure 1). Mosquito densities were assessed at time of randomization via CO₂-baited Centers for Disease Control and Prevention (CDC) mosquito traps. Thus, 1 trap would measure the mosquito density for a pair of campsites. Each trap was identically constructed according to a CDC trap design without use of the light source and

Figure 1. Map of study area.

was hung 10 m outside campsites at 1.5 m off the ground. The traps were set by the onsite coordinator 1 hour before dusk with a 1.5-kg block of dry ice as bait and were collected at 9:00 AM the next day. Mosquito sampling continued serially each week on the fourth night of camp throughout the study's 9-week duration. The principal investigator, also blinded, performed all mosquito counting and discarded nonmosquito insects.

The principal investigator performed data analysis. Data were entered into an Excel spreadsheet with tabulations performed with calculations designed before the study commenced, maintaining blinding. The primary outcome measure was the average number of mosquito bites or landings per person per night. For a 20% difference in mosquito bites, the sample size necessary for 95% power ($\alpha = .05$) was calculated a priori as 289 per group. Comparison of mosquito bites was performed by Wald chi-square test. Comparisons were expressed by the relative risk reduction (RRR) with 95% CI. Mosquito landing and bite rates were adjusted per campsite based on the campsite's mosquito population relative to the overall camp mean population (adjustment = campsite mosquito population $\div$ camp mean population). Ap-

proval from the Institutional Review Board was obtained.

Results

A total of 545 subjects participated in this study, encompassing 1614 person nights with 8156 mosquito bites or landings, hereafter referred to collectively as mosquito bites. The treatment group consisted of 761 person nights, and the control group consisted of 853 person nights. The sample was composed of 80% boys aged 11 to 18 years old and 20% adults >18 years old. Of those registered for camp ($n = 940$), 58% completed surveys.

The rate of mosquito bites was 5.1 ± 7.2 (mean $\pm$ SD) bites per 5-minute counting period for all subjects. Rates of mosquito bites are presented in the Table. The average number of nights counting mosquito bites was 3 of 4 nights requested. The permethrin-treatment group experienced an unadjusted RRR of 0.82 (95% CI 0.70 to 0.94; $P = .03$) for mosquito bites when controlling for insect-repellent use (Figure 2). When additionally controlling for mosquito populations as sampled at the campsites, the permethrin-treatment group experienced

Rates of mosquito bites*

Group	n	Bites (mean)	SD	RRR	95% CI	P	
Control No insect repellent	614	8.3	9.8	1	0.90 to 1.10		
Control Yes Insect repellent	239	4.9	4.9	0.59	0.43 to 0.74	<0.001	} 0.01
Treatment permethrin No insect repellent	481	3.9	5.2	0.47	0.36 to 0.59	<0.001	
Treatment permethrin Yes Insect repellent	280	4.0	5.6	0.48	0.33 to 0.63	<0.001	
Total control	853	7.1	8.6	1	0.91 to 1.09		
Total treatment permethrin	761	4.0	5.4	0.56	0.45 to 0.66	<0.001	

*"Bites" refers to both mosquito landings and bites per 5 minutes. RRR indicates relative risk reduction.

an RRR of 0.56 (95% CI 0.45 to 0.66; $P < .001$). The absolute risk reduction (ARR) was 3.1 (95% CI 2.4 to 3.9; $P < .001$) mosquito bites per 5 minutes (control 7.1 ± 8.6) with an RRR of 44.2% (95% CI 33.8% to 54.7%; $P < .001$) for mosquito bites at dusk. This extrapolates to a reduction of 36.2 bites per hour. Permethrin's efficacy did not change over the 9-week study duration.

Personal protection with insect repellent yielded an overall RRR of 0.69 (95% CI 0.57 to 0.81; $P < .001$). This protective effect occurred only in the control group (RRR 0.59; 95% CI 0.43 to 0.74; $P < .001$). In the treatment group, there was no statistical benefit for self-reported insect-repellent use (RRR 1.00; 95% CI 0.86 to 1.16; $P = .90$). This nonbenefit occurred with or without adjustment of mosquito populations. Even though posted signs in every campsite recommended the use of DEET insect repellents, usage occurred on only 32.2% (519 of 1614) of person nights. Only 14.9% of subjects consistently used insect repellents throughout all study nights. Comparing subjects in the permethrin-treatment group ($n = 761$) with subjects using insect repellent in the control group ($n = 239$), the permethrin group experienced significantly fewer mosquito bites (ARR 0.9 bites/5 min; RRR 0.82; 95% CI 0.67 to 0.97; $P = .02$). Comparing subjects not using insect repellent in the permethrin-treatment group ($n = 481$) with subjects using repellent in the control group ($n = 239$), the permethrin was still more protective (ARR 1.0 bites/5 min; RR 0.80; 95% CI 0.63 to 0.96; $P = .01$).

Serial mosquito sampling for 9 weeks did reveal variations among campsites. The campwide mean mosquito population was 86 ± 135 per trap. The mean mosquito populations sampled in campsites 1 and 2 were 139 ± 250 ; campsites 3, 4, and 5 were 61 ± 74 ; campsites 6 and 7 were 80 ± 108 ; and campsites 8 and 9 were 70 ± 85 mosquitoes ($P = .86$). Adjustment factors (ad-

justment = campsite population $\div$ camp mean population) were 1.59, 0.69, 0.91, and 0.80 per campsite group, respectively.

Discussion

Permethrin treatment of tents reduced the number of mosquito bites in the campsite areas at dusk by 44%. Permethrin treatment with or without insect repellent was more effective than personal insect repellent alone. Permethrin has been studied extensively worldwide in the treatment of clothing,^{9,19,20} blankets,²¹ and bed nets^{22–25} for protection against mosquitoes and malaria. Additionally, studies have shown that permethrin-treated clothing protects against ticks and treated wall hangings protect against sand flies.^{26,27}

Previous research has demonstrated permethrin-treated tents and bed nets reduce the incidence of malaria.^{24,25,28} A study involving 1 permethrin-treated tent showed that permethrin can reduce mosquito bites by 99.9% while a person sleeps inside a tent.¹⁵ Our study demonstrates that permethrin treatment of tents provides a spatial protective benefit for the immediate vicinity as well. As mosquitoes approach their prey, they land on surfaces such as tree branches or (in this study) tents before biting. Permethrin protects because of its insecticidal action rather than repellency, thereby reducing the biting population in the immediate area.²⁹

The CO₂-baited mosquito traps, when tested without nearby humans, trapped 900 mosquitoes per night in a pretest. The possible reason for decreased trapping during camp was the competition with nearby humans each emitting 200 mL·min⁻¹ CO₂.³⁰

In a summer-camp setting, where campers are often in their campsite but not necessarily inside their tents after dusk, treatment does confer a protective benefit for

Figure 2. Mean mosquito landing and bite rates are provided with 95% CIs.

the group as a whole. Even though handouts and posted signs recommended DEET-based insect repellents, only a minority of subjects (15%) in this study used repellent daily within 2 hours of dusk. Similarly, in a study of Australian soldiers in East Timor, only 19% used DEET daily, and DEET usage did not correlate with malaria.⁷ Also, during a dengue outbreak after Hurricane George, only 41% of relief workers used mosquito repellent daily.⁸ Interventions requiring active personal attention may be prone to failure, whereas systemwide passive interventions may be more consistently successful. In this regard, passive prophylaxis with permethrin tent treatment may be a viable public health option for camping and wilderness activities.

Permethrin is an inexpensive compound. The retail material cost of permethrin in our study was 90 cents per tent at 5 cents per person per week of camping. The bulk cost would be approximately 51 cents per tent.¹⁶ Permethrin application to clothing or fabric is also safe. Permethrin has a low volatility, and when applied to clothing only 3% of the chemical transfers to the skin after 7 days of continuous wearing.³¹ For medical uses, the 5% permethrin topical formulation is Food and Drug Administration pregnancy category B. It is nonstaining; nearly odorless; and resistant to degradation by light, heat, or immersion in water.^{32,33} However, although mammalian esterases rapidly metabolize permethrin, it

should not be used as a topical repellent because of neurotoxic safety concerns of chronic exposure.^{34,35}

Our study occurred in a thick deciduous forest; however, permethrin may photolyze within 2 months when exposed to prolonged direct sunlight.¹⁴ Unlike DEET, permethrin does not damage nylon, plastics, or painted surfaces.³⁶ It represents an inexpensive and safe method to reduce the number of mosquito bites and thereby reduce the burden of mosquito-borne illness, including viral encephalitis in North America and malaria worldwide.

STUDY LIMITATIONS

The largest limitation was that the 5-minute counts of mosquito bites and landings at dusk were self-reported. Ideally, observers would perform counts under strict conditions, but a degree of variability may occur in self-reporting. We sought to minimize the impact of any potential variability by conducting a large operational trial. Dusk was chosen for landing counts because it is the time of maximal mosquito activity. This is a subjective time, with a window of 32 minutes between sunset and twilight at the study location.³⁷ A strict time was not chosen because of the changing time of sunset (54 minutes) throughout the study's 9-week duration.

This study did not primarily investigate personal insect-repellent use. Previous studies demonstrated 99.9% protection when individuals used permethrin-treated clothing and DEET on exposed skin.^{12,29} Although the majority of commercially available repellents contain DEET, other products may have been used. Inquiry did not address the brand of repellent used, so as not to be too onerous. The study was well powered (95% α) to detect a 20% difference among groups; thus, the additive effect of repellent may be <20% with real-world application by adolescents. These factors may have accounted for the lack of difference with use of repellents among the permethrin-treatment group. A 2-hour window of previous insect-repellent usage was chosen for practical considerations, for subjects would have last been in their campsites and potentially applied repellent at lunchtime, which was 8 hours before mosquito counting and generally beyond DEET's effective duration.^{6,38,39}

Conclusions

Permethrin treatment of tents is a significant, safe, and inexpensive method of passive prophylaxis to reduce mosquito bites among all individuals in camping settings. Personal protection with insect repellent, though recommended, was rarely used. Permethrin treatment of a location provided more effective mosquito avoidance

for all subjects than did individual insect-repellent use alone.

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