

Effectiveness of Permethrin-treated Military Uniform Fabric Against Human Body Lice

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Military uniform fabric patches treated with permethrin were evaluated against natural and laboratory strains of human body lice, *Pediculus humanus*, L. Permethrin-treated fabric was toxic to body lice on contact and quickly affected feeding behavior and the likelihood of disease transmission, even when washed up to 20 times. The use of permethrin-treated clothing offers a new passive approach in human louse control not previously feasible. Military personnel wearing permethrin-treated uniforms, therefore, can expect significant and long-term protection from lice and louse-borne diseases in endemic areas.

Introduction

Human body lice (*Pediculus humanus*, L.) are still important public health threats in many areas of the world. This is of military concern because there are no licensed vaccines for louse-borne typhus or relapsing fever. Even if there were, vaccines to protect military personnel would not prevent epidemics in refugee or POW camps under U.S. military control. Lindane, the standard U.S. military pediculicide for over 20 years, is obsolete. Not only has it been identified as a potential oncogen by the U.S. Environmental Protection Agency, but most body lice are resistant to the organochlorine insecticides, including lindane.¹

The military all-purpose clothing impregnant, M-1960, is also obsolete. It was developed for the Department of Defense (DoD) by the U.S. Department of Agriculture (USDA) and introduced into the field in 1953. It has poor user acceptance due to its plasticizing properties, disagreeable odor, and skin irritation in sensitive individuals. It is also no longer manufactured, and unit stocks are nearly depleted. In addition, studies in the Far East in 1951 showed that M-1960 killed human lice slowly and provided poor protection to the wearer when in contact with louse-infested persons.²

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Permethrin, a synthetic pyrethroid, is under consideration by DoD as a candidate pediculicide for emergency louse control. It is currently marketed by Burroughs-Wellcome Co. as a 1% cream rinse for head louse control (Nix[®]) and has been used successfully as a dust formulation against body lice in Egypt.^{3,4} The U.S. Army is also studying permethrin as a replacement military uniform impregnant for M-1960. Its relatively safe toxicological properties and use as a clothing impregnant have been reviewed recently.⁵ Several studies have shown it to give a quick knockdown against a variety of arthropods, including mosquitoes and other biting flies,^{6,7} ticks,⁸ sandflies,⁹ chiggers,¹⁰ and black flies.¹¹ It has not yet been assessed as a clothing impregnant against human lice.

During World War II, studies were done in the United Kingdom, the Soviet Union, and the U.S. on the use of various chemicals for impregnating underwear to prevent louse infestations. This included pyrethrum, which was found to be effective, but only at high rates of application. Most of it also was removed by laundering.¹² Little research has been done since then on the use of repellents or impregnated clothing against human lice. This study evaluated the effectiveness of permethrin-treated military fabric against field and laboratory populations of body lice.

Materials and Methods

Field Tests

Field tests were conducted during September 1986, in Puno, Peru (elevation 3800 m), a frontier town located in the Andes Mountains on the West Shore of Lake Titicaca. A temporary laboratory was established in a small Peruvian Navy clinic in the town. Central heating was not available, and interior temperatures were erratically maintained using an electric space heater. The test plates containing lice were held under an electric-blanket to limit temperature variations. Temperatures, read with a remote probe, ranged from 24 to 28°C within the blanket. Ambient temperatures and relative humidity averaged 24°C and 23%, respectively.

Body lice used in the study were taken from 20 Peruvians living in the local area. All were males, and most were unemployed, ranging in age from 32 to 58. They wore long underwear over which were one or two pairs of pants, one to three shirts, and a coat and hat. They reportedly washed their clothes from 0 to 12 times a year, and the lice found on them were mostly concentrated on the clothing nearest the skin.

Prior to each test, lice were collected from one to three individuals by brushing them from the infested clothing into plastic holding containers. Mixed sexes of both adult lice and large nymphs were tested together.

Patches of temperate weight (NYCO, or 50%/50% nylon/

cotton) and summer weight (100% cotton) battle dress uniform (BDU) fabric, 10.5 cm², were treated with permethrin at a rate of 0.125 mg AI/cm². They were prepared by the USDA Insects Affecting Man and Animals Research Laboratory (IAMARL) in Gainesville, Florida, and provided by the U.S. Army Medical Material Development Activity, Ft. Detrick, Maryland. Untreated patches were used as controls. To determine the residual strength of the chemical, some patches were tested after being laundered, as described previously.¹³

Patches were tacked over aluminum foil on 13-cm² plywood boards. Three patches each of cotton unwashed, cotton washed once, and NYCO unwashed, and three untreated patches of corresponding fabric were used as controls in each test. The lice were divided randomly into lots of 10 or 20 (controls) in Petri dishes. Each dish of lice was inverted onto a fabric patch-board and held in place with rubber bands.

In one test, the lice were exposed continuously and knockdown was recorded at 5- to 15-minute intervals until all the lice were immobilized. Afterwards, they were transferred to an untreated patch, held for 12 hours, and observed for possible recovery. Four separate tests over a three-day period were completed.

To determine minimum effective exposure, lice from one volunteer were exposed for 0, 15, 30, and 60 seconds to a NYCO-treated, unwashed patch. They were then transferred to clean fabric and observed at ½-, 1-, 6-, and 12-hour post-exposure intervals.

Knockdown was recorded when the insect was on its back and unable to right itself or, if righted, was unable to crawl normally the length of its body. Natural mortality in the controls was corrected for by using Abbott's formula.¹⁴

Laboratory Tests

Laboratory tests were conducted in Baltimore, Maryland, to corroborate the field results from Peru and to test a larger number of different, washed fabric samples under more environmentally controlled conditions.

The tests were conducted in December 1986 at Insect Control and Research, Inc., in Baltimore, using a body louse colony (Orlando strain) originally obtained from the USDA IAMARL. The colony was previously adapted to feeding on rabbits, as described by Cole.¹⁵ Freshly fed, adult lice of both sexes were used in the tests.

The patch samples of temperate and summer weight BDU fabric included those unwashed and those washed 1, 5, 8, or 20 times. New patches were used in each series of the five tests to eliminate any possible variations in treatment rates.

The testing procedure was improved by placing 20 lice on fabric patches cut to fit tightly inside the bottom of a 100-mm Petri dish, and the top was added. Knockdown was recorded by lifting each patch out of the dish with forceps and then counting the number of lice unable to cling to the cloth. Earlier trials showed that this method gave readings similar to those in Puno, but was faster to perform and more readily demonstrated the effects of permethrin on the lice.

In one test, five repetitions of 20 lice per repetition were exposed to each fabric treatment. Lice were removed from the treated patches when 100% knockdown occurred and transferred to clean fabric. They were then held for 24 hours in a dark incubator at 24°C and 70% RH and observed for possible

recovery. Mean times to reach 100% knockdown were calculated for each of the treatments and analyzed using the Wilcoxin-Mann-Whitney test.¹⁶

To determine the effects of permethrin exposure on feeding behavior, 50 unfed lice were exposed to a NYCO-treated, unwashed patch for 60 seconds. They were then allowed to feed off the shaved belly of a restrained rabbit and held for 24 hours.

Results

Field Tests

Table 1 summarizes the results of four tests from the field study in Puno, Peru. No significant differences ($p > 0.05$) were found between the three fabric treatments. Nearly 50% of the lice were down in 15 minutes, all were immobilized at 75 minutes, and all were dead at 12 hours. The cotton patches washed once resulted in a lower per cent initial knockdown, but all lice were down at 75 minutes. Eggs were found on control patches, but not on treated ones.

Results of the minimum effective exposure tests are shown in Table 2. Over 50% of the lice exposed to a treated, unwashed patch for 15-60 seconds were knocked down within 60 minutes and all were dead at 12 hours.

In all tests, distinctive behavioral changes were noted in lice exposed to the treated patches as compared to the controls. From 1 to 5 minutes, the lice crawled around the rim of the Petri dish, similar to the controls; from 5 to 10 minutes, they appeared agitated and their movement was erratic. Many arched their abdomens into the air while others had difficulty moving forward, and some were immobilized on their backs. At 10 to 15 minutes, most were on their backs with only a few

TABLE 1
KNOCKDOWN OF BODY LICE TREATED FOR EACH OF
THREE FABRIC TREATMENTS*

| Treatment | Total Lice | Mean Per Cent Knockdown (KD) (minutes) | | | | | | | |
|-----------|---------------|--|------|------|------|------|------|-------|----------|
| | | 5 | 10 | 15 | 30 | 45 | 60 | 75 | 12 hr KD |
| COT-UNW | 120 | 0.0 | 23.3 | 48.1 | 75.7 | 90.7 | 96.7 | 100.0 | 100.0 |
| COT-W | 120 | 0.1 | 10.2 | 45.2 | 74.3 | 84.6 | 93.1 | 100.0 | 100.0 |
| NYCO-UNW | 120 | 0.0 | 18.9 | 44.4 | 82.0 | 87.9 | 92.5 | 100.0 | 100.0 |
| Controls | 180 | 0.1 | 0.1 | 0.1 | 0.1 | 1.2 | 1.2 | 1.2 | 8.9 |

COT-UNW = cotton unwashed; COT-W = cotton washed once; NYCO-UNW = nylon-cotton unwashed.

* Values are the means of four tests.

TABLE 2
KNOCKDOWN OF BODY LICE RECORDED FOR THREE SHORT-TERM
EXPOSURE PERIODS

| Exposure (seconds) | Total Lice | Per Cent Knockdown (hours) | | | |
|-----------------------|---------------|----------------------------|-----|-----|-------|
| | | 0.5 | 1.0 | 6.0 | 12.0* |
| 0 (control) | 57 | 0 | 0 | 4 | 10 |
| 15 | 25 | 68 | 64 | 100 | 100 |
| 30 | 30 | 40 | 57 | 100 | 100 |
| 60 | 28 | 32 | 50 | 93 | 100 |

* Lice all dead except for controls.

able to move forward normally. At 15 to 30 minutes, very few still showed coordinated movement; most were on their backs with legs twitching and were unable to stay upright if righted. At 60 to 75 minutes, all were on their backs with some leg movement still obvious. At 12 hours, most were dead, as evidenced by their darkened and shrunken appearance and the lack of leg, antennae, or gut movement.¹⁷ At 12 hours, the controls still showed normal behavior.

Laboratory Results

Table 3 summarizes the results of the laboratory study. For both the cotton- and NYCO-treated patches, the time to achieve 100% knockdown decreased as the number of washes increased. In all instances, however, 50% or more knockdown was obtained in 60 minutes, and 100% knockdown was obtained within 2 hours and 15 minutes post-exposure. For all but three treatments (cotton wash 8 and 20, NYCO wash 20), 90% knockdown was reached after 1 hour of exposure. No significant differences ($p > 0.05$) were found between any of the cotton- versus NYCO-unwashed or washed treatments (e.g., cotton-unwash vs. NYCO-unwash). There was a general decline in per cent mortality after 24 hours with an increase in the number of washes. More lice recovered on cotton (58%) than on NYCO (37%), and this difference was significant by chi square ($p = 0.001$). With few exceptions, those lice still down were dead. Those recovered appeared normal, and eggs were found on all but the unwashed patches.

Periodic observations showed the following for lice exposed to a treated patch for 1 minute and then allowed to feed: 21 were found feeding normally at 1 minute, only 8 were still feeding at 5 minutes, and none were feeding at 10 minutes post-exposure. At 5 minutes, some were unable to grip the skin and were rolling off the rabbit. At 15 minutes, all were off the belly with only two having obtained partial blood meals. All 50 were dead after being held on clean fabric for 24 hours. There was no mortality among lice fed at the same time during the routine rearing program.

Behavior changes similar to those observed in Puno occurred in the laboratory lice. The toxic effects were delayed, however, as the number of washes increased.

Discussion and Conclusions

Permethrin was found to be highly toxic to both the field and laboratory populations of human lice. Even after 20 washes, enough permethrin apparently remained in the fabric to give 99–100% knockdown within 2 hours. Some recovery occurred at 24 hours, but this was after the lice had been transferred to untreated patches. Schreck et al.¹⁸ observed that permethrin is resistant to washing and that the chemical is only gradually removed with each wash.

The NYCO patches had quicker knockdown and fewer recoveries than the cotton. This is advantageous since the temperate weight uniform would most likely be worn in cooler climates where body lice are often more of a problem.

In this study, permethrin rapidly affected locomotion and feeding behavior, with even 30- and 60-second exposures being toxic. The time required for a pediculicide to kill or prevent feeding is important for two reasons: 1) being unable to feed is the equivalent of death, and 2) since louse-borne typhus and relapsing fever are transmitted indirectly as a result of the bite of the louse, prevention of feeding may also lessen the threat of disease transmission.

There was little significant difference between the Puno and laboratory results in the per cent knockdown of lice following permethrin exposure. However, 100% mortality of the Puno lice was obtained on the cotton wash 1 patches, while for the laboratory strain, 49% recovered 24 hours post-exposure. The complete mortality of the Puno lice may be attributed to the less than optimal environmental conditions encountered (including low relative humidity); stress on the lice while being combed from the clothes; the need to use adults and large nymphs, fed or unfed; and/or possible differences in test procedures. Finally, if the laboratory strain had been confined to

TABLE 3
KNOCKDOWN OF BODY LICE RECORDED FOR EACH OF FIVE TREATMENTS AND TWO DIFFERENT FABRICS*

| Treatment | Total lice | Per Cent Knockdown (KD) (minutes) | | | | | | | | | |
|------------------------------------|------------|-----------------------------------|----|-----|-----|-----|-----|-----|-----|-----|----------|
| | | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 24 hr KD |
| Cotton (times washed) | | | | | | | | | | | |
| Unwashed | 100 | 80 | 99 | 98 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Wash 1 | 100 | 37 | 83 | 93 | 98 | 99 | 100 | 100 | 100 | 100 | 51 |
| Wash 5 | 100 | 9 | 45 | 86 | 92 | 99 | 100 | 99 | 100 | 100 | 19 |
| Wash 8 | 100 | 2 | 11 | 39 | 61 | 81 | 89 | 96 | 97 | 100 | 17 |
| Wash 20 | 100 | 1 | 31 | 69 | 77 | 91 | 95 | 98 | 99 | 100 | 24 |
| Controls | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| Nylon-Cotton (times washed) | | | | | | | | | | | |
| Unwashed | 100 | 72 | 96 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Wash 1 | 100 | 42 | 84 | 97 | 96 | 99 | 100 | 100 | 100 | 100 | 78 |
| Wash 5 | 100 | 15 | 65 | 84 | 91 | 94 | 98 | 100 | 100 | 100 | 70 |
| Wash 8 | 100 | 21 | 65 | 83 | 92 | 93 | 99 | 100 | 100 | 100 | 49 |
| Wash 20 | 100 | 2 | 21 | 50 | 70 | 89 | 93 | 99 | 100 | 100 | 19 |
| Controls | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 7 |

* Values are the means of five tests.

the treated patches longer, perhaps there would have been few, if any, recoveries.

This study shows that permethrin-treated fabric is toxic to body lice and will quickly reduce feeding behavior even on treated fabric washed 20 times. Lice recovered after 24 hours when they were removed from the washed fabric, but this would probably not occur under natural conditions outside the laboratory. Once intoxicated, the lice would either fall from the treated clothing or person to a hostile environment, or would soon be in contact with the treated fabric again.

As suggested by Eldridge (18), impregnated clothing can offer a passive means of effective louse control not previously feasible. While not appropriate for epidemic situations where large numbers of people must be quickly treated, it may offer more lasting means to reduce lousiness in endemic areas; for example, the issuance of treated clothing to patients with louse-borne disease or en masse during civic action programs or at refugee and POW camps. It would also reduce reinfestation opportunities by contact with infested individuals when worn by public health officials, medical personnel, and soldiers working in an endemic area. Incorporating the impregnant into mass laundry facilities would also lessen the need for non-emergency mass delousing. The long-term persistence of permethrin in clothing, even after 20 washings, means that re-impregnation requirements will be very low. Finally, individuals wearing treated clothing would also be protected from a variety of other biting arthropods, including ticks and fleas, and from diseases transmitted by these vectors.

While this study allowed for close observation of the effects of permethrin on lice, field tests with permethrin-treated clothing against natural populations of body lice would also be desirable. Such tests should include observations on any repellent and toxic effects of the chemical to lice and other ectoparasites, as well as studies on the use of impregnated underwear only.

We conclude that military personnel wearing permethrin-treated uniforms should expect significant and long-term protection from human louse infestations and louse-borne diseases. Our results further support the development of permethrin as a duct formulation to replace lindane as a military standard pediculicide for emergency mass delousing in epidemic situations.

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