*Active*Guard Mattress Liners
for Bed Bug Control

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The Genesis of Insecticide-Impregnated Fabrics

By Jim Ballard

Mosquito control is practiced over much of the world where malaria is endemic through the use of sprays of various organochlorine, organophosphate, carbamate and pyrethroid insecticides. Resistance in mosquito populations has been managed through the use of insecticide rotation and through the introduction of new classes of insecticides or other control technologies.

The use of netting, fabric or sheeting as a means of protection from flying insects has been in practice for a long time. Untreated bed nets were used during the construction of the Suez Canal in the early 1900s. The World Health Organization (WHO) implemented its 'Global Malaria Eradication Program' using netting in 1955.

INSECTICIDE-IMPREGNATED FABRICS. Since bed nets must be intact, and mosquitoes can still bite through the netting if it touches human skin, insecticide-treated nets (ITN) were developed in the 1980s with permethrin as the first (and most commonly used among the various pyrethroid insecticides) in fabric impregnation. ITN bed nets of one kind or another are now used throughout the 109 countries where malaria is endemic as part of a malaria control program. Mosquitoes that land on the net are either killed or repelled by the insecticide. Insecticide-impregnated fabrics also have been used to fabricate outerwear so that the garment repels flying insect pests.

While insecticide-treated sheeting has been used for mosquito control, it requires too much insecticide for treatment and blocks airflow. Though bed nets remain warm to sleep underneath in those tropical countries where they are largely used, net construction maximizes airflow and optimizes the technology and mosquito protection.

Fabrics used to make bed nets include: polyester, cotton, cotton-synthetic blends, nylon, polyethylene and polypropylene. Polyester is the most popular because it is lightweight, requiring relatively less insecticide (for impregnation) and water (limiting drying time). The warp is typically woven with a multi-filamentous material (36 or more). Bed net shape varies though most are hung over beds from the ceiling or a frame, and tend to be conical or rectangular in shape. Tents also have been constructed of bed net fabric.

Fabric strength is measured in dernier numbers; higher numbers indicating a stronger fabric. Dernier numbers between 75 and 100 are adequate for bed nets. Fabric mesh is measured in the number of holes per square inch with the smaller numbers indicative of larger holes. Most bed nets have a mesh size of 156 to 196.

ITN use typically has reduced the development of new malaria cases by 50%. Unfortunately, ITN bed nets need to be re-impregnated about every six months, which is a huge problem in rural areas where the nets are most frequently used. Once ITNs are in use in various countries, the logistics can be daunting for (1) getting insecticide to the net user, (2) reminding the net users to re-impregnate the nets, and (3) having the net user do it correctly.

Technological improvements occurred through the development of long-lasting insecticide nets (LLIN). These bed nets, made of 100% high-density polyethylene, are impregnated with the same pyrethroids, but these insecticides diffuse slowly through

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the threads and last for as long as five years. Typically, LLINs are purchased by donor groups such as the Bill and Melinda Gates Foundation and provided through the distribution network(s) within a given country. These bed nets avoid the need for constant insecticide re-impregnation.

It was not long before people using ITN bed nets discovered that these nets also provided partial or complete control of nuisance pests such as lice, ticks, cockroaches, flies and bed bugs. In fact, the additional control bed nets provided positively influenced the success of the mosquito control programs.

BED BUGS. Permethrin- or other pyrethroid-impregnated ITN bed nets developed for mosquito control are also used for bed bug (*Cimex lectularius* and *C. hemipterus*) control. Coincidentally, bed nets initially installed over beds to protect those sleeping from mosquito attacks have also had bed bugs observed crawling on the bed nets at night and bed bug control was achieved. Unlike mosquitoes, bed bugs lack the sticky pad between their tarsi and therefore do not exhibit the repellency behavior observed by mosquitoes. In contrast, bed bugs eventually obtain a lethal dose from the netting as they search for an entry to reach a host. As natural predators, such as ants, beetles and lizards, occupy outdoor spaces not frequented by bed bugs, migration of bed bugs has not been an issue thus true hitchhiking of bed bugs on belongings was the only means of spread.

Problems associated with the use of ITN bed nets in general arose from the fact that most bed nets were only effective for about six months and thus they had to be re-impregnated. People did not always remember to re-impregnate their bed nets nor was the distribution of insecticide in the re-impregnated bed nets homogenous. The end result was that bed nets eventually varied greatly in effectiveness through time.

In some villages, not all of the beds fitted with bed nets were maintained, resulting in situations where bed bugs received partial exposure to insecticides followed by a blood meal in the next bed with no bed net. The villages that came to have partial bed net use were the villages where insecticide resistance became an issue.

When all of the beds of whole villages used permethrin or alphacypermethrin-impregnated bed nets, and the impregnation rates were maintained, the bed nets remained effective in their control of bed bugs. Even after 14 years of use, no resistance issues were reported (Myamba et al., 2002).

New LLIN bed nets made of polyester or polyethylene impregnated with 2% permethrin have been found to have several years of life even when washed. This approach should help to reduce the chance of bed bugs encountering a poorly maintained bed net and may help prevent resistance development.

MODERN USAGE OF LLIN BED NETTING FOR BED BUG CONTROL. *Active*Guard® is a polyester fabric mattress liner impregnated with 1.64% permethrin. The fabric is similar in design and concept to some of the bed nets used in other countries for mosquito control except that *Active*Guard is installed directly on the mattress or box spring. The permethrin in *Active*Guard is effective for 24 months, at which point the liner is replaced. No washing or re-impregnation of the product is needed.

*Active*Guard is typically installed on a mattress and/or box spring after it has been cleared of bed bugs using a method or insecticide labeled for that use. The *Active*Guard Mattress Liner kills any missed bed bugs or newly hatched nymphs and prevents infestation of the mattress or box spring for 24 months. In this situation, *Active*Guard is part of an overall control program implemented by the pest management firm.

*Active*Guard also can be installed on the mattress and/or box spring that are not infested with bed bugs as a preventative strategy, especially in hotel rooms. A few bed bugs emerging from a guest's luggage can be killed when they contact the *Active*Guard liner.

The elements used within Integrated Pest Management (IPM) bed bug control programs, such as the use of heat, cold, decluttering, trapping, encasements and several classes of insecticides, should help prevent the development of widespread resistance where bed bugs cannot be controlled. The use of *Active*Guard to kill small numbers of bed bugs either within an IPM program or in a preventive situation should also result in minimal effect on resistance development.

CONCLUSIONS. Mosquito bed nets (ITN and LLIN) have been highly effective in reducing malaria rates in malaria endemic countries. The use of ITN and LLIN bed nets for bed bug control has been very effective and pyrethroid resistance avoided when all of the beds are protected by maintained bed nets. Bed bug resistance to pyrethroids has occurred when beds are protected by poorly maintained ITN and LLIN bed nets.

*Active*Guard Mattress Liners are an effective, modern adaptation of the use of LLIN bed netting for the control of bed bugs within an IPM program or within a preventive use strategy.

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Understanding Resistance in Bed Bug Populations

By Jim Ballard

The World Health Organization (WHO, 1957) defined "resistance" as "the development of an ability in a strain of insects to tolerate doses of toxicants that would prove lethal to the majority of individuals in a normal population of the same species." WHO also went on to say that they saw no valid process other than genetic that would result in said resistance.

There are many variables that can impact the reduction in the ability to control an insect population and many of these variables are under genetic control. This article seeks to explore the subject of insecticide resistance so that bed bug population management and control can be optimized.

Insecticide resistance to numerous organochlorine insecticides for both the bed bug, *Cimex lectularius*, and the tropical bed bug, *Cimex hemipterus*, was reported as early as 1948 (Busvine 1958). DDT-resistant bed bugs were also resistant to pyrethrins. Busvine (1958) also reported on two types of resistance that were described by two different groupings of organochlorine insecticides and not by modes of action. Furthermore, the pattern of resistance was following that of mosquitoes and houseflies. A more recent study (Tawatsin et al., 2011) reported both species of bed bugs collected from hotels in Thailand were resistant to numerous insecticides.

Other researchers (Moore and Miller 2006; Romero et al., 2007b; Yoon et al., 2008 and Lilly et al., 2009c) have reported bed bug resistance to pyrethroid and carbamate insecticides.

[Mechanisms of Resistance]

Behavioral

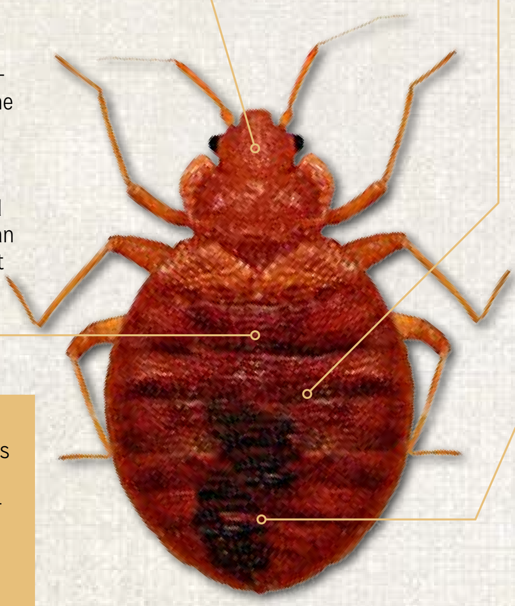
If an insect avoids an insecticide, it survives because it did not contact the insecticide. Bed bugs do not appear to be repelled by the commonly used pyrethroid insecticides (Moore and Miller, 2006 and Anon. 2008.) and bed bugs are often found resting on insecticide residues (Potter et al., 2006). When bed bugs were videotaped moving about on top of permethrin-treated fabric (*Active*Guard® Mattress Liner), there was no indication of repellency (Jones et al., 2013). One study (Romero et al., 2009a) reported that bed bugs did not appear to rest upon deltamethrin residues unless such treated surfaces contained feces or bed bug pheromones. Bed bugs that begin to move about after a low-level insecticide exposure are not displaying a repellent response.

Penetration

Insects, including bed bugs, have resisted insecticides be developing a thicker cuticle which reduces the amount of insecticide penetrating into the insect (Bai et al., 2011). Research findings are beginning to demonstrate that the cuticle of the bed bug is becoming more important in insecticide resistance (Zhu et al., 2013 and Koganemaru et al., 2013).

Target Site

Here the insecticide targets the voltage-gated sodium ion channels of the nervous system. Resistance occurs when the sodium channel exhibits reduced or no binding affinity to the insecticide. Bed bugs have displayed knock down (kdr) resistance (Adelman et al., 2011; Seong et al., 2010; Yoon et al., 2008; Zhu et al., 2010 and Zhu et al., 2013).



Metabolic

This resistance mechanism is simply the detoxification of the insecticide into a lesser or non-toxic form by the insect. Bed bugs have displayed this mechanism of resistance (Adelman et al., 2011; Bai et al., 2011; Karunaratne et al., 2007 and Zhu et al., 2013).

Transporters

Abc (ATP-binding cassette) transporters are involved with the movement of many types of molecules across membranes and play a role in insecticide resistance (Zhu et al., 2013). Typically, multiple mechanisms of resistance operate simultaneously which can confer higher resistance levels than one individual mechanism (Zhu et al., 2013).

Resistance Measurement Variables

When it comes to measuring insecticide resistance in a population of bed bugs, many test variables can have an impact on the results of the test. The test details associated with any study on bed bug resistance should be carefully reviewed, especially if several studies are being compared. Some of these variables would include:

Bed Bug Species (*C. lectularius* vs. *C. hemipterus*). The species of bed bug tested may not be an important variable. Liedtke et al., (2011) reported that antenna morphology and volatile blends were very similar between the two species. How and Lee (2010a and 2010b) reported similarities between the two species in development, feeding regimes, and survival following environmental changes. Newberry (1991) reported similar control mortality between the two species in laboratory tests using fenitrothion-treated paper. Tawatsin et al., (2011) reported resistance in both species of bed bugs to several classes of insecticides when bed bugs were collected from hotels in Thailand and tested in the laboratory.

Bed Bug Genetics. The genetics of the bed bug population used for testing is critical in that susceptible bed bugs are controlled by most products while field collected bed bugs may demonstrate various levels of resistance and different resistance mechanisms (Todd 2006 and Romero 2011).

Formulation. Standard emulsifiable concentrates or other similar formulations typically perform poorly after drying, as the residue is not readily picked up. Insecticides formulated as oil-based aerosols with multiple active ingredients; as a combination of a pyrethroid with a neonicotinoid; a new class of chemistry such as chlorfenapyr, particulate formulations such as dusts, wettable powders; and some microencapsulated formulations all appear to work much better and have longer residual activity than other formulations (Anon. 2012b; Kilpinen et al., 2011; Meyer 2012; Potter et al., 2012; Reid et al., 2010; Romero 2011; Romero et al., 2009b and Tawatsin et al., 2011).

The addition of the synergist piperonyl butoxide to formulated deltamethrin improved performance against some strains of bed bugs but had no effect on other strains probably because of differences in resistance mechanisms among the strains (Romero et al., 2009c).

Dose. The dose of insecticide that the bed bug is exposed to is critical to the test results.

Exposure Time. The amount of time the bed bugs are exposed to a treated surface is also critical to the results obtained. Bed bugs typically require a longer exposure time on treated surfaces because bed bugs do not move very much (as in a harborage). Exposure duration must be considered based upon the ease by which the residue

CAUSES OF RESISTANCE

Bed Bug Biology

Bed bugs, unlike most other insects, lack an arolium or sticky pad between their tarsal claws. Hence, bed bugs are poor climbers on smooth surfaces and very likely do not pick up dry non-particulate residual insecticides from treated surfaces. The reduction in exposure to insecticide residues results in sub-lethal exposure to insecticides, which is an excellent way to induce resistance.

Due to normal reproduction, bed bugs are inherently responsible for a degree of resistance found in the field. Romero et al., (2007a) reported that when pyrethroid resistant bed bugs were allowed to mate with susceptible bed bugs, the offspring exhibited an intermediate level of resistance.

Formulation

Insecticides formulated as water-based, non-particulate insecticide formulations typically kill bed bugs following a direct application. However, once these formulations dry and adhere to a surface, it is difficult for the bed bug to take up the dry insecticide. The result, again, is exposure to sub-lethal doses (Tawatsin et al., 2011).

Cross Resistance

Organochlorine insecticides, such as DDT, were heavily used in the past in the control of bed bug populations. Bed bugs quickly became resistant to DDT and then to alternate organochlorine insecticides used to replace DDT. Organophosphate resistance along with carbamate resistance soon followed. Unfortunately, resistance to DDT also confers a level of resistance to pyrethroid insecticides because of similarities in mode of action. When the bed bug resurgence started around the year 2000, water-based, non-particulate pyrethroid insecticides were used to control them. Control issues were apparent (Tawatsin et al., 2011).

Poor Treatment Methods

The control of bed bug infestations using the wrong insecticides or with treatment practices that are not thorough or within a property poorly prepared for treatment results in many bed bugs receiving sub-lethal doses of insecticides, which leads to control failure and more poor applications (Jones and Bryant, 2012).

can be picked up by the bed bugs, i.e., its bioavailibility.

Direct Treatment Methods. How bed bugs are directly treated in the laboratory can be important. Insecticides mixed in water and applied to the bed bug can form a bead that either falls off of the bed bug or exhibits poor penetration compared to an insecticide mixed in a better penetrating solvent (Lilly, 2009a). Direct injection of measured amounts of insecticide into adult bed bugs also has been used (Adelman et al., 2011). Resistant bed bugs that are sprayed or dusted directly typically die eventually (Anon. 2007).

Residue Exposure/Test Substrate. Residual testing results can often depend upon the formulation applied and the substrate it is applied to. Filter paper can capture the insecticide making it less available to the bed bug compared to a glass surface (Lilly, 2009b).

Time Of Day. Optimal bed bug activity has been reported to be between 3 am and 6 am (Mellanby, 1939). Testing bed bugs during daytime laboratory work hours may result in a significant reduction in activity, a key variable in insecticide residue testing.

Bed Bug Stage Tested. To avoid variation in data resulting from testing the smaller sizes of bed bug nymphs, most work is completed using adult bed bugs. Laboratory trials centered upon deltamethrin suggested that adult males could be used exclusively for testing thus preserving the adult females for colony expansion (Feldlauffer et al., 2013).

Time From Last Feeding. Under optimum conditions, bed bugs feed every five or six days (Mellanby, 1939). Testing bed bugs within several days of feeding may result in bed bugs with reduced activity as they seek to hide and digest their meal while bed bugs within one or two days of feeding are more fragile and mortality as a result of handling can occur (Dr. S. Jones, 2012, personal communication). Fasting for six or more days increased bed bug activity and improved residual test data (Jones, S. 2012, unpublished research).

Test Arena. Bed bug testing may be performed in Petri dishes, various vials with internal harborage surfaces, treated panels of one substrate or another, tunnel systems, with or without attractant heat, carbon dioxide or pheromones, all of which makes comparative data analysis challenging.

Lab vs. Field Studies. Facilities that perform bed bug research typically have one or more field strains that exhibit high levels of pyrethroid resistance (usually determined through deltamethrin screening). The susceptible bed bug populations are commonly the Harold Harlan strain or an occasional USDA strain. Laboratory testing involving pyrethroids typically reveals poor efficacy because of resistance or the formulation selected for testing.

Field testing, on the other hand, typically reveals that applications of pyrethroid insecticides eventually result in the control of the bed bug infestation. Field applications applied directly to the bed bugs are effective. The residual of most pyrethroids is poor due to the formulation selected. In contrast, the residual of pyrethroids formulated as a dust, wettable powder or combined with a neonicotinoid insecticide has been very efficacious in the control of bed bugs (in the laboratory and the field).

Resistance Ratio. There is a lot of variation in the determination of the Resistance Ratio (RR) based largely on test methods. Many bed bug populations collected from the field, tested to reveal high pyrethroid (usually deltamethrin) resistance, begin to lose their resistance after a few years in the laboratory (Dr. D. Miller, Jan 2011, National Bed Bug Summit, Washington, D.C.; and Zhu et al., 2013). Another researcher reported that a bed bug population collected from the field was found to have a RR of 1400 but dropped to a RR of 2 after a few years (Dr. A. Romero, Mar 2012, EPA SAP for Bed Bug Product Testing Guidelines, Washington, D.C.). It was also reported (Anon. 2012a) that a combination of hydroprene and deltamethrin resulted in a 20% reduction in the Resistance Ratio of bed bugs resistant to deltamethrin, which should improve the performance of this combination.

Resistant Strain Fitness. Many researchers have commented upon the lack of fitness observed in bed bug populations collected from the field. These populations were found to have high levels of pyrethroid (usually deltamethrin) resistance. The lack of fitness is usually revealed in laboratory experiments where control mortality increases above 10% usually due to the length of the test. Mortality effects have been noted in controls in a few as eight days for highly resistant bed bug test populations (Dr. S. Jones, personal communication).

Polanco et al., (2011a) reported that when they determined the life table analysis for three populations of bed bugs (high, medium and low resistance RR) exposed to no stress variables in the laboratory, that the most fit population was the least resistant one. Polanco et al., 2011b then reported that when populations of bed bugs in the laboratory were stressed (starved) that highly resistant populations had a higher vulnerability to mortality due to starvation.

Exposure of Bed Bugs to Active Liners

A unique and effective tool in the control of bed bugs is the use of active mattress liners. These liners, such as *Active*Guard® Mattress Liners, are impregnated with permethrin and can kill bed bugs and prevent infestation of a mattress and box spring. One major advantage in the use of this mattress liner is that it can kill bed bugs for two years. Given that bed bugs can live up to five months without feeding it is important to use control measures with long life so that the bed bugs do not outlast all elements of a control program. The exposure of small numbers of bed bugs to an active liner should not present an issue from the standpoint of increasing resistance.

In addition to mortality, a secondary finding for bed bugs exposed to the mattress liner was the significant reduction in feeding to repletion for the five strains that fed through the liner fabric (Jones et al., 2013). The impact of reduced feeding upon the development of any bed bug populations is unknown but research is in progress.

Active liners can be used within an IPM control program as the final treatment step. Once the mattress and/or box spring is cleared of bed bugs, an active liner is installed to kill any bed bugs that were missed and any that emerge from missed eggs; also, to prevent bed bugs from harboring on the mattress or box spring.

Active liners can also be installed as a preventive tool where the mattress and or box spring is protected from introduced bed bugs in un-infested hotel rooms. Small numbers of dead bed bugs have been observed on top of active liners (Ballard et al., 2011) when the liners are used in this way.

DISCUSSION. An analysis of the genetic structure of bed bug infestations revealed that within the continental United States there was high genetic diversity as well as within cities. This suggests that there were numerous bed bugs introductions into the United States (Schal et al., 2011 and Booth et al., 2012). In contrast, bed bugs within a room are often highly inbred and likely the result of a single mated female. In larger buildings or older infestations, more than one bed bug introduction may have occurred.

Despite the evidence that bed bug resistance to pyrethroids has been readily found in the field, many pest management firms report satisfactory results using this insecticide class (Romero et al., 2007a). With a pest that is so difficult to control, most PMP firms use an Integrated Pest Management (IPM) approach in their control program that also helps to manage resistance.

Today, the use of heat, cold, steam, vacuum, direct application of insecticide to clear sleeping surfaces, vastly improved residual formulations, insecticide cocktails, dusts for the wall voids, fumigation, encasements, active mattress liners and canine inspections (Ballard, 2010) are all used in bed bug control protocols. The vast array of tools used in the control of bed bugs should influence the genetics of the bed bug populations.

CONCLUSIONS. Pyrethroid-resistant populations of bed bugs are commonly found in the field. The test variables used in any bed bug resistance study should be closely reviewed to determine the impact on the results of the study. Most bed bugs can still be killed with pyrethroid insecticides if directly treated. Residual pyrethroid insecticides can control bed bug populations if properly formulated. Modern treatment methods, used in an IPM program, should act to reduce or slow the progression of insecticide resistance.

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