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Prevention, Identification, and Treatment Options for the Management of Bed Bug Infestations

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evidence review

Summary

- In the past decade, bed bug infestations have been increasing worldwide.
- Historically, studies have failed to provide evidence for the transmission of human diseases through bed bugs, but recent evidence is lacking.
- Although physical reactions to bed bug bites continue to be documented, evidence regarding the mental health effects arising from bed bug infestations is limited to anecdotes and case reports.
- This report provides an update and summary of the bed bug management strategies discussed during a workshop at the 2010 Canadian Public Health Association Conference.
- ‘‘Best practices’’ regarding prevention, identification, and treatment options are presented, using evidence from existing evaluative studies.
- Awareness of bed bug behaviour and proper building maintenance can prevent transfer of bed bugs from belongings, including second-hand items, and reduce entry points and harbourage sites.
- In addition to inspection by trained professionals, early recognition of clinical symptoms and environmental signs of an infestation are important to avoid further spread of bed bugs and to allow implementation of safe and effective treatment options.
- Early findings may indicate a need for special support for vulnerable individuals with mental health issues potentially exacerbated by bed bug infestations.
- Preparing units for treatment, including the removal of clutter, is essential. However, physical and financial limitations are challenges for managing bed bug infestations, especially for vulnerable populations.

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- Current treatment options such as application of heat or pesticides can be effective when properly implemented,but there are concerns with pesticide resistance.

- An Integrated Pest Management approach is recommended and should include ongoing monitoring and prevention that are essential for positive treatment outcomes.

- Regulatory officials, building management, and pest management professionals are encouraged to collaborate using a systematic approach to address bed bug infestations.

Introduction

In the last decade, bed bug infestations have become widespread in North America,[1,2] Europe,[3,4] Australia,[5] Asia,[6,7,8] and Africa.[9] Bed bugs are appearing in hotels, hospitals, libraries, dormitories, multi-family housing units, and even single family homes.[10] Despite awareness of bed bugs by the general public, researchers, government agencies, and pesticide companies, there is limited scientific evidence that evaluates management options for this pest.

Adult bed bugs (Cimex lectularius) are small (6–7 mm; nymphs are 1–3 mm) and elusive insects that exclusively feed on the blood of.[11,12] They are light- to reddish-brown in colour and generally hide and lay their eggs in crevices, bed frames, mattresses, and behind baseboards.[2,6] They can travel 5-20 feet each way to feed every 3-7days if hosts are available, and they can survive without feeding for up to one year.[13,14,15,16] Adult bugs can lay up to 200–500 eggs over their lifespan and eggs can hatch in 1–2 weeks.[17] Bed bugs can reach breeding age in 6–8 weeks and multiply to levels that can lead to infestation within a matter of months.[17]

Physical health effects associated with bed bugs include allergic reactions and hypertrophic scarring.[18] Although allergic reactions may appear immediately or 7–11 days post-exposure, individuals without previous exposure to bed bug bites may appear asymptomatic.[19] Reinhardt et al. (2009)[19] proposed that repeated exposure to bites can sensitize individuals, decreasing the latency between bite and skin reactions (e.g., 10 days to a few seconds after five exposures). Bed bug bites may often occur in a linear or cluster configuration on exposed areas such as arms, legs, torso, and face.[11] Individuals may develop papular urticaria (hives) and (or) bullae (fluid-filled lesions) which may be treated with topical or oral corticosteroids, antibiotics, and (or) antihistamines.[18] Systemic health effects are rare but include anaemia, asthma, and anaphylaxis.[20-23]

Evidence for bed bug related mental health impacts such as depression, loss of appetite, insomnia, social isolation, suicidal thoughts, and (or) hypervigilance are limited to case reports and anecdotal reports, many of which highlight experiences of vulnerable individuals.[11,24] Experiences with bed bugs may also disrupt sleep and, if severe, result in subsequent physiological and neurocognitive health effects associated with sleep loss.[11] Recently, a survey of online anecdotal postings regarding bed bugs found that a variety of symptoms reported are compatible with those of post-traumatic stress disorder.[25]

Although transmission of human disease through exposure to bed bugs has not been shown, the potential for bed bugs to act as vectors for numerous human pathogens, including human immunodeficiency virus (HIV), hepatitis C virus (HCV), and hepatitis B virus (HBV), is reviewed by Chen and Copes (2010), Delaunay et al. (2011), and Goddard and deShazo (2009).[17,25,26] Of the infectious pathogens considered in these reviews, only HBV has been suggested as a potential candidate for transmission through bed bugs. This suggestion relies on studies that demonstrate the isolation of HBV antigen or DNA from bed bugs and (or) their excretions. Recently, methicillin-resistant Staphylococcus aureus (MRSA) and vancomycin-resistant Enterococcus faecium (VRE) have been recovered from bed bugs in the infested dwellings of three hospitalized patients (conditions for hospitalization not specified) from an impoverished community.[27] The potential for secondary skin infections and bloodborne infections relating to bed bugs continues to be of interest to public health agencies and researchers.

Methods

Participants of a workshop at the 2010 Canadian Public Health Association (CPHA) Conference examined the re-emergence of bed bugs in Canada, discussed the state of bedbug science, and compared the approaches of municipal and public health authorities in four large Canadian cities regarding bed bug control. Several bed bug management guidelines were initially identified, and management options were tabulated by the authors (Table 1, Table 2, Table 3). This report summarizes the management strategies discussed at the workshop and identifies ‘‘best practice’’ prevention, identification, and treatment options. Pertinent evaluative studies were

located using the Summon search engine within the University of British Columbia Library website (http://www.library.ubc. ca/summon/). A list of publishers indexed in Summon is available at http://www.serialssolutions.com/en/resources/detail/summon-participating-publishers. The specific management options were used alone or in combination with one or more of the following search terms: bed bug, Cimex lectularius, prevent*, identif*, treat*, manage*, strateg*, control, option*, efficac*, effectiv*, and evaluat*. Search results were refined and limited to peer-reviewed publications in English and excluded newspaper articles. Articles from 2000–2012 were chosen in preference. Included articles guided manual searching of bibliographies, journals, databases, and grey literature.

Results and Discussion

Management strategies

Although prevention of bed bug infestations is the ideal management strategy, vigilant efforts are not always successful, and eliminating infestations requires an approach that involves thorough inspection, cleaning, treatment, and follow-up. Collaboration between residents, building management, pest control professionals, and (or) regulatory officials is often required to manage bed bug infestations.[28-30] Integrated Pest Management (IPM) is an approach that combines these strategies with information on pest biology, infestation severity, and sustainable interventions for determining effective management options. IPM is recommended for addressing bed bug infestations as it considers health, economic, and environmental impacts of potential interventions.

Depending on factors such as the type of inspection, preparation, treatment, and extent of infestation, bed bug management costs can range from hundreds to thousands of dollars per infested unit.[31] Prevention, identification, and treatment options are summarized in Table 1, Table 2, and Table 3, respectively.

Prevention

Generally, poorly maintained multi-unit buildings with a high occupancy turnover are more prone to building-wide infestations.[31] These conditions increase the likelihood of bed bug migration through cracks or crevices in building infrastructure (walls, pipes, windows, etc.) that provide entry points between units and harbourage sites.[31,32] Proper building maintenance can help prevent ingress of bed bugs (e.g., repairing floorboards, walls, and windowsills, and removing loose wallpaper).[33] Encasing mattresses and box springs helps mitigate and limit the size of infestation by preventing the ingress and egress of bed bugs from these items. Isolating the bed by elevation and bed bug moats or interceptors may also prevent bed bugs from climbing up bed posts.[33]

Table 1. Options for preventing bed bug infestations

Type of Control	Description	Effectiveness	Limitations	Evaluations
Sealing	Using a sealant (e.g., silicone-based), to prevent movement through cracks, crevices, and entry points into wall voids.	Restricting the movement of bed bugs can help and prevent bed bugs from migrating and infesting other units.	Difficult to identify and seal all entry points. Does not eradicate harbourage sites.	None found
Isolation of bed and furniture	Moving the bed and other furniture away from walls (and each other) to discourage migration to host and facilitate inspection.	May help with reduction of bites while other means are pursued.	Does not eradicate harbourage sites.	None found
Plastic dish with oil, double-sided tape, and petroleum jelly as a barrier	Plastic dish with oil, petroleum jelly, or double-sided tape can be used at bed legs to act as a temporary barrier.	No research available	No research available. Petroleum jelly can damage surfaces. A break in the barrier reduces effectiveness.	None found
Metal furniture	Using metal furniture in place of wood or other materials (e.g., metal bed frames).	Bed bugs do not travel on metal and plastic as easily as other surfaces. Fewer harbourage areas facilitate inspection.	If metal is not kept clean and rust-free, bed bug movement is not impaired.	None found

Table 1 (continued)

Type of Control	Description	Effectiveness	Limitations	Evaluations
Moat-style interceptors and portable monitoring devices	Trapping bed bugs either in a moat (with talcum powder coating the sides) that can be placed under bed legs or on sticky substance placed near hot spots. Heat, carbon dioxide, and pheromones have also been demonstrated to lure bed bugs into traps.	Useful for confirming infestations and determining the extent of infestations. Can be cost-effective as it may be used prior to a full consultation. May prevent infestations from spreading to adjoining units.	Possibility of ''bridges'' (e.g., blankets on floor, bed skirt, or headboard on the wall) where bed bugs can bypass interceptors. Some portable devices are costly and have limited availability. Some bed types or frames are not compatible with moat-style interceptors. Issues with aesthetics, especially if used in hotels or similar accommodations. Attractants may not last for extended periods of time and may need to be replaced.	(32,34-38)
Clutter removal	Removing clutter so that bed bugs have fewer harbourage areas and to increase chances of finding them. Need to ensure that clutter is bagged before removal to prevent migration to other areas.	Useful for identifying harbourage sites and to increase effectiveness of other control methods.	May be difficult to ensure tenants remove clutter before treatment, especially for tenants who are physically or mentally unable.	None found
Encasements	Enclosing mattress and box spring and other furnishings in impermeable covers to prevent harbourage of bed bugs inside or prevent bed bugs from escaping. Can aid in inspection and be useful before or after an infestation is found.	Prevents bed bugs from infesting household items, and also eventually kills any bed bugs inside items. Only effective if containment is complete and not removed prematurely. Aids in salvaging items.	Does not eradicate harbourage sites that are not encased (e.g., walls). As a control method, items needs to be left enclosed for long enough to kill the bed bugs and all stages (> one year). Only effective if containment is complete. Must ensure encasings are properly zipped or sealed as small gaps can provide entry or exit of bed bugs.	None found

Table 2. Options for identifying bed bug infestations

Type of Control	Description	Effectiveness	Limitations	Evaluations
Plastic dish with oil, double-sided tape, and petroleum jelly as a barrier	Plastic dish with oil, petroleum jelly, or double-sided tape can be used at bed legs to act as a temporary barrier.	No research available	No research available. Petroleum jelly can damage surfaces. A break in the barrier reduces effectiveness.	None found
Moat-style interceptors and portable monitoring devices	Trap bed bugs either in a moat (with talcum powder coating the sides) that can be placed under bed legs or on sticky substance placed near hot spots. Heat, carbon dioxide, and pheromones have also been demonstrated to lure bed bugs into traps.	Useful for confirming infestations and determining the extent of infestations. Can be cost-effective as it may be used prior to a full consultation. May prevent infestations from spreading to adjoining units.	Possibility of ''bridges'' (e.g., blankets on floor, bed skirt or headboard on the wall) where bed bugs can bypass interceptors. Some portable devices are costly and have limited availability. Some bed types or frames are not compatible with moat-style interceptors. Issues with aesthetics, especially if used in hotels or similar accommodations.	(32,34-38)
Canine detection unit	Inspection of a premise by a specially trained detection dog accompanied by a trained handler. Guidelines for testing or certification may be useful to ensure consistency and accuracy (e.g., by the National Entomology Scent Detection Canine Association or the National Pest Management Association).(National Entomology Scent Detection Canine Association 2011; National Pest Management Association 2011).	Useful, especially in large areas, for confirming infestations, determining the extent of infestations, and monitoring bed bug treatments.	Expensive to train and hire. Possibility of false positives. Variability in training and accuracy of dogs. Some may not be able to distinguish between viable and nonviable eggs.	(39,40)
Clutter removal	Removing clutter so that bed bugs have fewer harbourage areas and to increase chances of finding them. Need to ensure that clutter is bagged before removal to prevent migration to other areas.	Useful for identifying harbourage sites and to increase effectiveness of other control methods.	May be difficult to ensure tenants remove clutter before treatment, especially for tenants who are physically or mentally unable.	None found

Table 2 (continued)

Type of Control	Description	Effectiveness	Limitations	Evaluations
Vacuuming	Vacuuming bed bugs and eggs from mattress, furnishings, carpeting, cracks or crevices, etc. A designated vacuum with high efficiency particulate air (HEPA) filters is recommended to reduce beg bug allergens from dispersing into the air. Vacuum bags should be bagged and sealed before disposal.	Can reduce initial populations and help identify recent bed bug activity. Can reduce use of pesticides. Allows follow-up inspections to determine if there are more bed bugs.	Does not pick up eggs well. Does nothing to eradicate harbourage sites. Vacuum may infest or re-infest areas. Improperly discarded vacuum bag can be a source of infestation.	(41-43)

Table 3. Options for treating bed bug infestations

Type of Control	Description	Effectiveness	Limitations	Evaluations
Clutter removal	Removing clutter so that bed bugs have fewer harbourage areas and to increase chances of finding them. Need to ensure that clutter is bagged before removal to prevent migration to other areas.	Useful for identifying harbourage sites and to increase effectiveness of other control methods.	May be difficult to ensure tenants remove clutter before treatment, especially for tenants who are physically or mentally unable.	None found
Disposal of infested items	Disposing of furnishings that are heavily infested that cannot be treated or encased easily. Discarded infested items should be clearly identified to discourage salvaging. Care must be taken not to reintroduce bed bugs with replacement second-hand items.	Can reduce the level of infestation and maximize the effectiveness of other treatment methods.	Can be financially burdensome. If not properly handled and destroyed, may propagate the bed bugs elsewhere. Other prevention and management options must also be used as disposal of infested items will not eliminate an infestation.	None found

Table 3 (continued)

Type of Control	Description	Effectiveness	Limitations	Evaluations
Encasements	Enclosing mattress and box spring and other furnishings in impermeable covers to prevent harbourage of bed bugs inside or prevent bed bugs from escaping. Can aid in inspection and be useful before or after an infestation is found.	Prevents bed bugs from infesting household items and also eventually kills any bed bugs inside items. Only effective if containment is complete and not removed prematurely. Aids in salvaging items.	Does not eradicate harbourage sites that are not encased (e.g., walls). As a control method, items needs to be left enclosed for long enough to kill the bed bugs and all stages (> one year). Only effective if containment is complete. Must ensure encasings are properly zipped/sealed as small gaps can provide entry/exit of bed bugs.	None found
Vacuuming	Vacuuming bed bugs and eggs from mattress, furnishings, carpeting, cracks/crevices, etc. A designated vacuum with high efficiency particulate air (HEPA) filters is recommended to reduce beg bug allergens from dispersing into the air. Vacuum bags should be bagged and sealed before disposal.	Can reduce initial populations and help identify recent bed bug activity. Can reduce use of pesticides. Allows follow-up inspections to determine if there are more bed bugs.	Does not pick up eggs well. Does nothing to eradicate harbourage sites. Vacuum may infest or re-infest areas. Improperly discarded vacuum bag can be a source of infestation.	(41,43,44)
Heat	Containerized heat treatment or heating of a living space to sufficient temperatures to kill bed bugs and their eggs. Temperatures and times vary, although heating to 48˚C for 72 minutes has been demonstrated to kill eggs. May be a good option for cluttered homes where preparation is a problem.	Useful alternative to reduce populations quickly and minimize the use of chemicals. No chemical residue. Effective for killing all stages. Less preparation required as effects of heat are not substantially impaired by cluttered environments.	Difficult to get core temperatures of materials up to temperatures. Difficult to get houses up to this temperature especially in cold weather. Can damage some materials. Lethal heat levels must be reached quickly to prevent acclimatization and dispersion of the bed bugs.	(45-47)

Table 3 (continued)

Type of Control	Description	Effectiveness	Limitations	Evaluations
Steam	A nozzle of steam is moved across materials at a rate of 15 seconds/linear foot. Recommend application of steam treatments by a professional to avoid dispersion of bed bugs.	Kills all stages within a short exposure time. Less costly than dry heat and fumigation. No chemical residue. Most useful strategy for undamaged mattresses.	Takes a long time to treat large areas. Difficult to get into all areas and to steam furnishings thoroughly. If applied with too much pressure, bed bugs may be dispersed. Heat and moisture can damage material. No residual activity.	None found
Freezing	Placing items in a freezer or using dry ice (solid-liquid phase carbon dioxide) to kill bed bugs and eggs. Cooling must be quick because bed bugs can acclimatize and survive cold temperatures.	Some evidence indicates freezing at –17˚C for 2 hours can kill bed bugs and their eggs. The efficacy of dry ice has not been researched. Household freezers are an easily accessible and inexpensive method to treat small items. No chemical residue.	Household freezers may not be capable of maintaining these temperatures, and take extended periods of time to reach sufficiently low temperatures (e.g., 8 hours to reach –17˚C), or have inadequate space to treat infested items. Variables such as material, size, and complexity of an item make it difficult to ensure all surfaces of an object reach the required temperatures. Dry ice is expensive and may not penetrate into all harbourage areas. Direct treatment option only. Pressure from dry ice dispenser may promote dispersion.	(12,45,48,49)

Table 3 (continued)

Type of Control	Description	Effectiveness	Limitations	Evaluations
Laundering	Laundering if dirty, in hot water (e.g., 60˚C) and detergent for at least 30 minutes. Drying clean clothes in dryer on hot setting for at least 30 minutes. Cannot transport dirty and clean laundry in same container. Dissolvable (alginate) bags or washable bags can be used. Most dry-clean only items can be dried without damage.	Laundering facilities and equipment are easily accessible and typical high heat settings are effective at killing all stages of bed bugs. Dry-cleaning with perchloroethylene is also shown to be effective at killing all stages.	Can be costly if using commercial laundry services. Care when handling clothing and (or) using communal laundry facilities is required to prevent migration of bed bugs. Not everything can be laundered.	(49)
Pyrethroids	Synthetic contact pesticide similar to pyrethrins produced by flowers of pyrethrums. Many have little residual effect and therefore a follow-up application is usually needed to ensure that newly hatched bed bugs are killed in a second application. Consultation with pest management professional is required.	Kills all stages of bed bugs, yet exclusive reliance on insecticides has not always proven successful in effectively eliminating bed bugs. Relatively fast acting (minutes to hours) on susceptible bed bug strains.	Resistance is becoming more common. Only works as a contact insecticide. Short half-life (about 3 days) with no residual effect. Dispersion of bed bugs at sub-lethal concentrations. Preparation is required to ensure all harbourage areas are treated.	(50-57)
Diatomaceous earth	Desiccant dust applied in areas that bed bugs harbour or travel. Consultation with pest management professional is required.	Long lasting residual activity. Long shelf life. Can be used preventatively in cracks and crevices.	Ineffective for eggs and adults not travelling across the diatomaceous earth. Takes two weeks to work.	(35,58)
Dichlorvos	Organophosphate insecticide that volatilizes for specific space treatment of clothes, closets, etc. Consultation with pest management professional is required.	All stages, including eggs killed in approximately 7 days. Use of fan and heat to increase volatilization of strips has been shown to decrease time needed to achieve 100% mortality in all stages (e.g., from 7 days to approximately 4 days).	Highly toxic and used for treatment of closed spaces only.	(50,56,59)

Table 3 (continued)

Type of Control	Description	Effectiveness	Limitations	Evaluations
Chlorfenapyr	A pyrrole insecticide with slow acting residual properties. Often used as an alternative to pyrethroids. Consultation with pest management professional is required.	When used as part of an IPM program, bed bugs were eliminated from 50% of infested units in an apartment building within 10 weeks. Achieved 86% reduction in bed bug populations after 8 weeks. Dry residues remained fully insecticidal even after 4 months.	May take days to weeks to kill bed bugs. Bed bugs do not avoid treated areas. Eggs and nymphs survived after 14 days of exposure.	(35,56,57,60-62)
Fumigation	Sulfuryl fluoride gas is introduced into an infested unit or building to kill bed bugs and eggs. Can also be used for containerized treatments. Consultation with pest management professional is required.	Penetrates into objects and difficult to treat areas such as wall voids. May be cost-effective option when preparation or treatment of unit is difficult due to heavy infestation or clutter. Single treatment can achieve 100% mortality of all stages of bed bugs.	Residents must vacate premises during and after fumigation to allow for treatment and aeration, respectively (e.g., 2 days). Extensive preparation for buildings required (tarps, seals, etc.). Expensive option that requires specialists who are not available with all pest management companies.	(63)

Second-hand items. As bed bugs can be brought in through used furniture, equipment, bedding, books, or clothing, one strategy for reducing the chances of introducing an infestation is to increase education and awareness regarding the sale and purchase of second-hand items.[64] Inspecting items for signs of infestation, bagging and washing items, avoiding higher risk items (e.g., mattresses, upholstered furniture, curbside items), and contacting a pest management professional if a potential infestation is identified are recommended to prevent bed bug infestations arising from second-hand items.[64] Organizations that distribute second-hand items are encouraged to foster practices that minimize the potential for the transfer of bed bugs and develop protocols for accepting, handling, and disposing these items.

Luggage and accommodations. To avoid bringing home bed bugs, travellers can take a number of precautions.[65] Accommodations should be checked for signs of bed bugs (blood spots, feces, molted skins, etc.), especially on mattress seams and the headboard and mattress interface. Luggage may be encased in sealable bags to prevent bed bug entry and placed off the floor such as in the bathtub, hung in the closet, or on luggage stands until the unit is checked. Management should be notified if signs of infestation exist and another nonadjacent room or accommodation should be sought. When returning home, travellers should thoroughly inspect luggage and launder or dry all clothing using the warmest setting appropriate for the fabric. However, some dryers may not reach the temperatures required to destroy bed bugs. Luggage may be thoroughly vacuumed to remove bed bugs and the vacuum bag should be immediately removed and sealed in plastic bags before disposal.

Identification

Identifying bed bug infestations early increases the chances of successful treatment.[33] However, surveys in the United Kingdom have indicated that the general public is often unaware of the appearance of bed bugs.[66] Recognizing the clinical signs indicative of bed bug bites can help with detection, but some individuals are

asymptomatic, making detection of bed bugs more difficult until visible signs of bed bugs are evident.[67]

Live or dead bed bugs, molted skins, fecal deposits, or small blood stains can indicate infestation. Common harbourage areas include beds, box springs, bedding, baseboard and carpet edges, nightstands, dressers, upholstered furniture, walls, ceilings, clothing, and appliances.[68] In multi-unit dwellings, all units adjoining an infested unit should be inspected systematically (above, beside, across, and below). If bed bugs are found, assessments should be made to identify harbourage sites and estimate population size.

However, visual inspection alone may miss bed bugs and underestimate the actual number.[35] Consulting a trained and qualified pest management professional is essential to determine the extent of the infestation. Monitors including sticky traps, moat-style interceptors or traps that use heat, carbon dioxide, or pheromones as lures, can aid in determining the size of bed bug populations.[36,69] Furthermore, moat-style interceptors have been shown to be more effective than visual inspection for estimating numbers and detecting infestations.[37] Canine detection units have been used for locating bed bugs and monitoring treatments. Studies have reported that trained dogs have a detection rate of 11–95% when bed bugs are present, but there is a lack of peer-reviewed evidence and field evaluations.[39,40] Moreover, effectiveness depends upon proper training of both the dog and the handler (e.g., certification).

Treatment

The increase in bed bug infestations has focused attention on the options for bed bug control. However, there is only a limited amount of data and research that would enable effective practices to be selected on the basis of clear evidence.[70] Assistance from trained pest management professionals is essential for providing treatment options and for monitoring the effectiveness. Preparation of occupied spaces is a necessary first step for treatment.[65,71,72] Generally, eradication of bed bugs requires both chemical and nonchemical treatments and takes more than one application, so follow-up, usually after a two-week period, is often necessary due to the emergence of nymphs from surviving eggs laid before the initial treatment.[33]

Preparation. Removal of clutter can help reduce, identify, and expose harbourage areas to facilitate treatment. Potentially infested items should be inspected, bagged, treated, and isolated from the infested dwelling until the infestation is eliminated. Clothing and bedding should be laundered and stored in plastic bags while treatment is underway. Severely infested furniture should be isolated, marked, heat treated (if available), and properly discarded. Furniture that is not removed should be moved away from the wall (e.g., at least half a metre) to facilitate treatment. Areas should be thoroughly vacuumed and cleaned before treatment to remove bed bugs. To ensure that bed bugs do not scatter to neighbouring units during treatment, units adjacent to and across from an infested unit should be prepared for treatment as well. Some health agencies have provided support for preparation of homes (e.g., Toronto and Winnipeg – Case Study 1).

Case Study 1: Bug and Scrub at Toronto Public Health (TPH)

Between 2008 and 2010, the City of Toronto Shelter, Support, and Housing Administration accepted a temporary social enterprise called ‘‘Bug and Scrub,’’ whereby homeless men were trained in preparing units before treatment. The program provided low-cost, reliable, nonjudgmental assistance to the most vulnerable in preparing for pesticide treatments. Services included removal of all infested items, steam treatment, extreme cleaning, laundering, assistance with case management, follow up inspections, and maintenance. Although the Bug and Scrub program ended in 2010, this internationally recognized support model is currently being used in Australia and Manitoba.

Chemical options. Although approved insecticides from different chemical groups are often required for treatment, they are limited in availability and insecticide resistance is well known.[73,74] Pyrethroid insecticides are most prevalent, but there are increasing issues with resistance, lack of residual activity, and dispersion of bed bug populations when exposed to sub-lethal levels.[57,75,76] Diatomaceous earth dehydrates bed bugs, but it takes days or weeks to kill them, and it cannot be applied as widely as other products.[35,58] Nevertheless, its residual activity, long shelf life and lower risk of inducing resistance due to its physical mechanism of action are advantageous properties.[65] Limestone is not as effective in the field and one study found that it took eight weeks to achieve high mortality.[61] Silica with pyrethrins has been shown to induce higher water loss in bed bugs than diatomaceous earth, and the addition of pheromone to silica dust increased its activity.[58] Trained and qualified pesticide applicators should be consulted for applying chemical treatments.

Nonchemical options. Bed bugs and their eggs have been reported to have an upper thermal tolerance of approximately 46˚C and will not survive much longer

than 1 hour at this temperature.[48] Heat and steam have been successful at killing bed bugs and their eggs, but it is often expensive and potentially damaging to heat an entire house. For example, typical temperatures for whole-room heat treatments reach approximately 45–52˚C for several hours, which requires ambient temperatures of 55–65˚C and the need for special heating equipment and preparations.[46] Kells and Goblirsch (2011)[46] concluded that heat treatment at 48˚C for 71.5 minutes is required for eliminating all stages of bed bugs. Some property managers have resorted to building heat rooms to heat belongings before occupants move in (Case Study 2). Less information is available about the effectiveness of freezing, although some studies indicate that temperatures of –16 to –18˚C for 1 or 2 hours can kill bed bugs and their eggs.[48] Laundering with hot water (60˚C) and detergent for dirty clothes and (or) drying clean clothes on the hottest cycle (> 40˚C) for a minimum of 15–30 minutes have been successful in killing bed bugs at all stages.[49]

Case Study 2: Hot Rooms in Social Housing (J. Wilson, personal communication, 4 March 2011)

B.C. Housing is the provincial Crown agency that develops, manages, and administers a wide range of subsidized housing options in British Columbia for those in greatest need. They have developed guidelines for constructing heat treatment rooms as part of an Integrated Pest Management (IPM) program that is being adopted by operators of subsidized housing. Currently, B.C. Housing has built two heat rooms in Vancouver's Downtown Eastside and this resulted in a considerable drop in infestations in their housing stock. The protocol involves ''baking'' all of a tenant's belongings before entry into the building and heating belongings of units affected by bed bugs.

In 2007, the B.C. government purchased a single room occupancy (SRO) hotel and renovated it. During renovations, IPM practices were implemented such as placing diatomaceous earth inside walls, double sealing electrical sockets, and sealing wood base boards twice to contain any bed bugs that might gain entry into a unit. The SRO also has one heat room (a ''bed bug sauna'') that has made a substantial difference in reducing the incidence of bed bug infestations. In addition to having tenants heat and launder belongings before moving in, established tenants are asked to do this at the door when they bring in items from outside. When the SRO does have an infestation, it is usually contained to one unit owing to the IPM strategies implemented during renovation. To prevent and identify problems early, monthly inspections (more often, if warranted) and as-needed educational workshops with tenants are conducted by property management. Also, home support workers are asked to report infestations to property management. Building managers indicate that one of the greatest contributors to successful control of bed bugs is to instill a sense of community among the tenants, so that they realize that bed bug problems affect everyone and are not simply a problem for staff.

B.C. Housing is piloting a new way of doing heat treatment in its housing stock; it just recently purchased four portable heaters that are used to heat rooms. The treatment protocol involves heating rooms to 54˚C for 4 hours. Approximately a dozen sensors are placed throughout the room to monitor temperature and ensure that the required temperature is reached during heating. They move these heaters from room to room, progressively treating a building.

Ineffective treatments. Placing items in a black plastic bag in the sun or raising the thermostat in the home may not kill bed bugs.[77] As well, ''foggers" and ''bombs'' containing insecticide will not kill most bed bugs; it may increase migration to other areas and could potentially pose a health risk to occupants. Once liquid pesticides are dry, they lose their effectiveness. The insecticidal action of boric acid requires the ingestion of the acid and is therefore ineffective for bed bug control as bed bugs exclusively feed on blood.[33]

Improper use of insecticides. Pesticides such as pyrethroids or pyrethrins, carbamates, and organophosphates may result in adverse health effects when misused.[78,79] Acute health effects include neurologic, respiratory, cardiovascular, gastrointestinal, ocular effects, and even death.[79-81] In the United States, one report identified 111 cases of illness associated with pesticide exposure during bed bug treatments in three states from 2003 to 2010.[79] Almost all were associated with exposure to pyrethroids or pyrethrins. Moreover, pesticide application by uncertified home occupants was noted in 39% of cases, including one fatal case. Less evidence is available on chronic health effects of these pesticides, but cancer and developmental effects have been suggested .[80,82-84]

New treatment options. Recent alternative ideas for control of insects include the targeting or manipulation of obligate endosymbiotic bacteria required by the insect.[85,86] As these symbionts are required for bloodmeal digestion, reproduction, or development, interfering with these processes may reduce populations.[16,86] The insect growth regulators currently used on a variety of arthropod pests prevent nymphal stage bugs from molting to become an adult, preventing reproductive maturity.[87,88] Insecticide synergists such as piperonyl butoxide have also been suggested as a

possible option to address resistance.[89] To date, studies have shown some potential for these products and they are often incorporated into other insecticides, but more research is needed to understand if these options are effective as bed bug control agents and in real-world environments.[61]

Conclusion

The incidence of bed bug infestations is increasing, along with resistance to commonly used pesticides. Getting rid of bed bugs is challenging. Acting on opportunities to create awareness and to educate the public regarding bed bugs may increase early detection of infestations, improving outcomes. As new bed bug prevention, treatment, and control options continue to be explored, numerous guides, handbooks, summaries, and fact sheets have been produced in an attempt to capture the ‘‘best practices’’ and inform governments, pest management professionals, property managers, and residents of bed bug management strategies. An approach consistent with IPM practices is likely to yield more desirable outcomes for salvaging household items, reducing unnecessary exposure to insecticides, minimizing disruption of human activities, and controlling the spread of an infestation. By involving regulatory officials, building management, and pest management professionals, a systematic approach to address a bed bug infestation is possible; this would involve inspecting the property for bed bugs, assessing the extent of the infestation if one exists, implementing specific controls, and monitoring treatment outcomes. These strategies should include methodologies that have been evaluated to be feasible, safe, and effective for long term control. With the large number of bed bug control methods available, there is a need to have a formal evaluation of their outcomes and of cost effectiveness. Publishing and reviewing community and regulatory experiences of major infestations may facilitate discussions to inform practice and policy. Furthermore, surveillance systems, updated evidence regarding health impacts, and evaluative reports on management options can guide the response of public health professionals and pest management professionals in addressing bed bug infestations.

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