Practical Solutions for Treating Laundry Infested with *Cimex lectularius* (Hemiptera: Cimicidae)

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The common bed bug, *Cimex lectularius* (L.) (Hemiptera: Cimicidae), is a widespread human ectoparasite in temperate areas. Although relatively uncommon in developed countries in the second half of the 20th century, since ~2000, there have been reports from several countries including the United Kingdom (Boase 2001), Australia (Doggett et al. 2004), and the United States (Pinto 1999) of a substantial increase in the number of reports of infestations. In London, work by Richards et al. (2009) has shown that the number of reports of infestation are rising at ~25% per year. Bed bugs are most commonly found on beds and mattresses and in crevices close to the bed. However, they may also seek harborage among clothing stored close to the bed, or may become entangled with bed linen while this is being changed. Once associated with clothing or linen, there is a risk that bed bugs may then escape insecticide treatments, and may be transported to new locations.

Most bed bug control involves the use of insecticides. However, linen and clothing are not normally treated with insecticides, so nonpesticidal techniques such as laundering, are often suggested as a means of disinfecting such items. A survey by the author in April 2007 of 100 Websites relating to bed bug control showed that although most sites offered advice on laundering or other processing of clothing and soft furnishings, specifics such as temperatures and times were often lacking or varied greatly between sites. Advice typically included reference to 'hot washing,' 'tumble drying,' and 'dry cleaning.' Despite this widespread advice, there is very little evidence for the effectiveness of these procedures in controlling bed bugs, although Speare et al. (2003) has reported the effects of domestic washing and drying on the survival of head lice.

In terms of basic data on thermal sensitivity, Bacot (1914) studied survival of common bed bug eggs and nymphs exposed to a range of temperatures and other physical conditions, whereas Mellanby (1932) determined thermal death points. Potter et al. (2007) summarized some tests and experiences of domestic procedures for killing common bed bugs within clothing, but the temperatures reported within washing machines and dryers appear in general to be much higher than those used in the United Kingdom. On a more pragmatic level, Doggett et al. (2006) looked at the potential of common bed bugs to survive on mattresses encased in black plastic and left in sunlight, and found that the temperatures reached were insufficient to cause complete mortality. Doggett’s study in particular underlines the need to subject traditional wisdoms and conjecture to rigorous scientific testing before promoting their use as standard codes of practice.

The objective of the work described here was to establish the effectiveness of various procedures available...
to the general public, including soaking, washing, tumble drying, dry cleaning, and freezing, that may be used to rid clothing, linen, and soft furnishings of bed bugs.

**Materials and Method**

**Insect Cultures.** Stock cultures of bed bugs were originally sourced from Insects R & D Ltd. (formerly the Medical Entomology Centre), United Kingdom, in 1998 and have since been housed at the University of Sheffield, United Kingdom, in an incubator at 26 ± 1°C and 70 ± 5% RH, with a cycle of 12L:12D. Bugs were fed weekly on New Zealand white rabbits using the protocol of Davis (1956). All procedures involving rabbits adhered to the United Kingdom Animals (scientific procedures) Act 1986, and were covered by United Kingdom Home Office licenses.

Adult bed bugs were collected from the stock cultures and thus represented a spread of ages from 1 wk to 6 mo postecdysis. Third instar nymphs were reared together in cohorts and kept for 1 wk from their last ecdysis to allow for full hardening of the cuticle.

All eggs were laid within a 2 d window by freshly fed, mated females, which were isolated on a strip of filter paper measuring 10 × 20 mm. To avoid damaging the eggs we did not attempt to separate them from the filter paper.

**Experimental Setup.** Thin cotton pouches, 40 wide × 80 high mm, sealed with a sandwich bag clip, were used to isolate the bed bugs within the laundry. Ten adults, 10 third instar nymphs, and 10 eggs were placed in each pouch. Three replicate pouches were placed inside the pockets of garments in each load and three replicate loads were run in each treatment making a total of 90 adults, 90 nymphs, and 90 eggs per treatment. For each treatment, three replicate pouches of bugs were placed on the bench top and left at room temperature for the duration of the respective treatments as no-treatment controls.

**Treatments.** Washing was conducted with 3.2 kg dry weight of laundry in a domestic front loading washing machine (Zanussi FJR154) set at 30, 40, or 60°C, using 50 ml Ariel nonbiological detergent, a standard product widely available on supermarket shelves. The washing cycle never exceeded 30 min. All tests were conducted in Sheffield, United Kingdom, where the water is of medium hardness. Data loggers (TinyTag Plus: TGP-1500, United Kingdom) were used to confirm the accuracy of the temperature settings and were found to be within ±2°C.

Tumble-drying was conducted with 3.2 kg dry weight of laundry in three identical tumble dryers (Huebsch Originators: Loadstar II, United Kingdom). The machines were set to either “cool” or “hot” and run for 10 or 30 min. Data loggers were used to assess the changes in temperature throughout the drying cycles.

Cold soaking was conducted in 3.2 kg dry weight of laundry over 2 and 24 h. The linen was fully submerged in ca. 15°C medium hardness tap water without detergent for the duration of the treatment.

Dry-cleaning was conducted by a professional dry-cleaning service using perchloroethylene. Although other dry-cleaning agents are used for specialist cleaning, perchloroethylene is the solvent most commonly used by dry cleaning services available to the general public. Nine pouches of bed bugs were placed in the pockets of three suits (three pouches in each suit). The technician was requested not to press the suits after cleaning.

Freezing was conducted in two stages. Firstly, to confirm the work on cold tolerance of common bed bugs by Kemper (1936), pouches containing the bugs were placed directly into a −17°C freezer and survival was assessed after 2 h. To determine how long a bag of dry laundry takes to cool to −17°C, data loggers were placed in the center of a 2.5 kg bag of loosely packed laundry, which was then placed into the freezer drawer of a standard household upright fridge freezer (Zanussi: Z1921/SFFA) with a minimum temperature of −18°C.

**Assessment of Survival.** Survival of the active stages was assessed immediately after treatment or, in the case of the freezing trial, once the bugs had returned to room temperature. Egg survival was assessed as hatching success, after removing them from the pouches and incubating them at 26 ± 1°C and 70 ± 5% RH for 1 wk to allow for any viable eggs to hatch.

**Results**

In the washing trial, only the 60°C wash achieved total mortality in all life stages. The 40°C wash was sufficient to kill the active stages but not the eggs (Table 1).

In the tumble-drying trial, only the “hot” cycle run for 30 min was sufficient to kill all life stages (Table 2). The data loggers revealed that the temperature in the “cool” cycle never exceeded 30°C (Fig. 1), which is well bellow the published thermal death point of bed bugs of 40–

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**Table 1.** Percentage survival of adults, nymphs, and eggs washed at 30, 40, and 60°C

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Adult survival</th>
<th>Nymph survival</th>
<th>Egg survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot, 30 min</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Hot, 20 min</td>
<td>98.9%</td>
<td>98.9%</td>
<td>98.9%</td>
</tr>
<tr>
<td>Hot, 10 min</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

a Average of three replicates, 10 individuals per replicate.

**Table 2.** Percentage survival of adults, nymphs, and eggs tumble-dried on a “cool” and “hot” cycle for 10 and 30 min

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Adult survival</th>
<th>Nymph survival</th>
<th>Egg survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. treatment control</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Cool, 10 min</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Cool, 30 min</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Hot, 10 min</td>
<td>15.6%</td>
<td>24.4%</td>
<td>5%</td>
</tr>
<tr>
<td>Hot, 30 min</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

a Average of three replicates, 10 individuals per replicate.

b Range.
45°C (see Mellanby 1932, Johnson 1940). The “hot” cycle did exceed 40°C but it took >15 min to reach this temperature, which could explain the only partial mortality in the 10-min cycle. Cold soaking for 24 h was sufficient to kill the active stages but had no effect on survival of the eggs (Table 3). Dry-cleaning with perchloroethylene resulted in 100% mortality of all life stages.

Freezing for 2 h at −17°C killed 100% of all life stages, supporting the work of Kemper (1936). The data from the temperature loggers revealed that it takes ≈8 h for the temperature in the center of a 2.5 kg bag of dry laundry to fall to −17°C (Fig. 2).

Discussion

The basic results presented here on temperatures and bed bug mortality are broadly similar to those presented by Speare et al. (2003) on head lice, with a cold wash giving no mortality, whereas a hot wash (66°C) and a hot dry (68°C) both resulted in complete mortality. The results also agree well with previous findings on thermal death points. Research by Kemper (1936) showed that exposure to temperatures of −17°C for 2 h was required to kill common bed bug adults and eggs. Research by Mellanby (1932) showed that exposure of 1 h at a temperature of 45°C was required to kill eggs and adults. The work presented here demonstrates that these earlier findings can be used in general terms as predictors of the performance of domestic appliances in terms of disinfection. No previous data are available on the efficacy of dry cleaning with perchloroethylene against bed bugs.

Hand-washing of garments was not evaluated here. However as this is typically carried out at no >40°C, it is unlikely to kill all bed bug stages.

Successful management of bed bug infestations in residential properties requires inputs from the pest control organization, such as inspection, insecticide treatment and the provision of advice, whereas the resident is expected to prepare their premises for treatment and to follow advice on disinfection of linen and clothing. Although it is relatively unusual for infestations to be entirely contained within linen or clothing, those bed bugs that do harbor within such items are believed to be important in terms of the spread of infestation from place to place. Most pest control organizations will therefore recommend that residents process these items themselves to destroy any bed bugs concealed within them.

In practice, however, the work carried out here shows that the choices facing the resident are complex. Effective laundering requires a minimum of 60°C, but some fabrics cannot be washed at this temperature. Effective tumble-drying also requires temperatures that are unsuitable for some fabric types. The alternative of dry-cleaning is again suitable for some fabric types only, and is costly. Deep-freezing will be suitable for some items, but many households may not have access to a deep-freezer that will reach −17°C, and is large enough to contain useful numbers of items. On the assumption that processing of potentially infested laundry items should be the responsibility of the resident rather than the pest control organization, then the challenge is to present this information to the resident in a way that clearly sets out the options and implications. It is worth noting that while dry-cleaning may be an effective means of disinfection for some items, there is also a potential risk of facilitating the spread of bed bugs through taking infested items to the dry-cleaners, particularly if the dry-cleaner is not made aware that the items should be treated as potentially infested. The same applies to the use of public laundrettes where residents do not own their own washing machines and/or tumble driers.

Table 3. Percentage survival of adults, nymphs, and eggs after soaking in 15°C water for 2 and 24 h

<table>
<thead>
<tr>
<th>Treatment time (h)</th>
<th>Adult survival</th>
<th>Nymph survival</th>
<th>Egg survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. treatment control</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>2</td>
<td>84.4%</td>
<td>76.7%</td>
<td>100%</td>
</tr>
<tr>
<td>24</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
</tr>
</tbody>
</table>
In addition, there are regional differences in the operation and performance of domestic appliances that stress the importance of understanding the local situation when making recommendations. For example, washing machines in Europe typically heat their water to the user-selected temperature, whereas washing machines in the U.S. and Australia tend to use the household hot water supply and are therefore limited by the temperature of the water coming from the boiler. Furthermore, wash cycles in the U.K. typically last 90–120 min, whereas in the U.S., wash cycles of 20–30 min are much more common (Procter 2000). As Tables 1 and 2 demonstrate, differences in temperature and duration may make the difference between success and failure in terms of clothing disinfection. These differences emphasize the need for caution when considering adopting advice generated in one country, for use in another.

Recommendations for high temperature washes for bed bug control also need to be set against the trend in some countries toward cooler washes, as part of a national campaign to reduce domestic energy consumption (Defra 2007). No tests were carried out on the tropical bed bug C. hemipterus. However, as there are differences between the temperature sensitivity of this species and C. lectularius (Omori 1941), the findings of this study may not be directly applicable to C. hemipterus.

Acknowledgments

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References Cited


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Fig. 2. Temperature change over time at the center of a 2.5 kg bag of dry laundry in the freezer drawer of an upright household fridge freezer (Zanussi: Z1921/SFFA) with a minimum temperature of −18°C.