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The bed bug problem: Past, present, and future control methods

Reina Koganemaru *, Dini M. Miller

Department of Entomology, Virginia Tech., Blacksburg, VA 24061, USA

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ABSTRACT

Bed bugs are wingless hematophagous ectoparasites that have co-existed with humans since they first appeared in the caves of Mediterranean and Middle Eastern regions approximately 65 million years ago. Bed bugs are not known to transmit diseases, most probably due to the lack of sylvatic cycles. Historical control methods include some remedies, but also many useful control methods such as community-wide eradication efforts, insecticidal powders, fumigation, and rigorous cleaning. These intense eradication efforts combined with newly developed synthetic insecticides, such as DDT and malathion, almost eliminated bed bugs during the 1950s. However, there has been a resurgence in bed bug populations during the past 15 years. Recent molecular evidence suggests that bed bugs did not experience a genetic bottle neck, but rather existed in isolated populations. Today, bed bugs are found to have multiple modes of insecticide resistance including reduced cuticular penetration and up-regulation of ABC transporters (ATP-binding cassette protein transporters). Currently available chemical treatments are based on pyrethroid insecticides that are not effective against many insecticide resistant bed bugs, but fumigation and dust formulations have been found to be more effective. Non-chemical control methods are most useful in community-wide integrated pest management. Future bed bug control will most likely to rely on refining the currently available methods and focusing on the research with cooperative efforts.

1. Introduction

1.1. Origin of bed bugs

Bed bugs are obligatory hematophagous ectoparasites that have been one of the most common and annoying pests in human history [1–3]. Adult bed bugs are wingless, reddish brown, approximately 5 mm in length, and dorsoventrally flattened, resembling unfed ticks or cockroach nymphs [2,4]. Bed bug nymphs are translucent, yellowish white in color, and range 1–4 mm in length approximately [2,4]. Bed bugs are believed to have evolved in caves within the Mediterranean [1] and Middle Eastern regions [2], where they were parasites of bats and birds, aggregating in their nests [2]. The exact period of bed bugs emergence is unknown, but ancestral bed bugs are most likely to have evolved approximately 145–65 million years ago (mya), since hematophagous arthropods appeared at six times independently during Jurassic and Cretaceous periods [5], and most of the modern insect fauna was established by 65 mya [6].

Bed bugs are believed to have adopted human hosts when humans started living in the caves of the Middle East and Europe [1,2], sometime during the Pleistocene, Paleolithic, and Neolithic periods [2]. Morphological evidence and the geographical distribution of the Cimex species that feed on bats suggests that bed bugs have probably not originated in Africa [2]. The host–parasite relationship between humans and bed bugs became more established as humans transitioned from their transient lifestyle as hunters gatherers to a more stable community of farmers living in villages [1,2] ca. 8000–5000 B.C. [2]. The earliest records of bed bugs living with humans are those from Greece by 400 B.C. [1,2]. Other bed bug records were discovered from Italy in 77 A.D., China in 600 A.D., Germany in the 11th century, France in 13th century, and England by the late 1500s [1,2]. The first bed bug records in North America date from the 1600s [1,2]. There are at least 57 names used to refer to bed bugs, the majority of them belonging to European, Middle Eastern, and Western Asian languages [2].

Bed bugs, bat bugs, and bird bugs taxonomically belong to the blood feeding family Cimicidae [2,3]. The Cimicidae is one of only two families along with Reduviidae (triatomine) within the order Hemiptera that are blood feeders [7]. All other families of Hemiptera feed on plant tissue fluids [7]. Numerous species of bat bugs and bird bugs have been documented from the nests of bats, swallows, purple martins, swifts, woodpeckers, pigeons, and chickens throughout the world [2,3]; within the New World, parakeets, parrots, and various raptor species such as vultures, eagles, hawks, and owls have also been parasitized with cimicid bugs [8]. Among the 92 species of Cimicidae recognized currently in the world, 16 species were reported in North America [3]. Bat bugs and bird bugs

* Corresponding author. Address: 216 Price Hall, Virginia Tech., Blacksburg, VA 24061, USA. Fax: +1 540 231 9131.
E-mail address: reinak7@vt.edu (R. Koganemaru).

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primarily feed on their host animals, however they can feed on humans as well, when the nests of the bats and birds are present in domesticated structures and the primary host animals become absent [3].

Only three cimicid species are known to be human ectoparasites [2]: These include Lepto-cimex boueti Brumpt which is present in West Africa [2,5] and primarily feeds on bats but can also feed on humans [5], *Cimex hemipterus* F. found in tropical and subtropical regions [2,3,5] including Florida [3], and *Cimex lectularius* L. which is distributed worldwide but is most prevalent in temperate regions [2,3,5]. All three species of the human bed bugs also feed on bats and chickens, and the common bed bug, *C. lectularius* L., occasionally feeds on domesticated animals [2].

1.2. Medical importance

Bed bugs are known to cause emotional distress, sleeplessness, and anxiety in those people who live with bed bug infestations in their dwellings [9]. Bed bug bites can also potentially cause allergic skin reactions [2–4,10,11]. The bites can be severely irritating [9,12], resulting in a rash with clusters of pruritic, erythematous papules, or wheals as a result of the repeated probing by a single bed bug or multiple bed bugs [4,9,10,13,14] searching for a capillary space from which to feed. An immunoblot analysis using human serum with the common bed bug, *C. lectularius* L., salivary gland extracts and recombinant bed bug saliva proteins found that specific human Immunoglobulin E (IgE) antibodies react with the 32 kDa *C. lectularius* nitrophorin [15]. This study suggests that IgE-mediated hypersensitivity to the bed bug nitrophorin is the cause of skin allergic reaction [15]. The severity of the skin reactions vary significantly among different individuals [16]. Allergic skin reactions to bed bug bites will range from no reaction to a red rash accompanied by intensive itching, that may result in swelling, or even scarring depending on the individual's specific immune response and previous exposure history [16]. The severity of the skin reactions varies significantly among individuals from no reaction to intensive itching, swelling, or scarring for an extended period of time, depending on the previous exposure to bed bugs and various immune responses to protein antigens in the bed bug saliva [15]. Due to this high variability on the reactions, bed bug bites should not be diagnosed solely by skin reactions [16]. The reappearance of bites for a prolonged period of time can be indicative of a bed bug infestation, caused by some other biting insect, or some medical complication. Secondary skin infections from scratching the bites, asthma, anaphylactic reactions [10,15], and sometimes anemia and iron deficiencies in infants and elderly, have been reported in association with high infestations [10,13,17].

To date, there has been no significant evidence of bed bugs transmitting any pathogens that cause human diseases [4–6,11,14,18]. An extensive review of the possible disease transmitted by bed bugs in 1963 reported 32 disease pathogens found from bed bug body parts (gut, head, proboscis, hemocoel, salivary glands, malpighian tubules, hemolymph, midgut and hindgut, intestine, rectum, coelomic fluid, legs, and excreted feces) after being fed infected animals or blood [14]. However, consistent experimental replications showing bed bugs ability to transmit human disease pathogens have been absent [4,5,11,14]. A recent publication showed bed bugs were infected with human Hepatitis B virus (HBV) through feeding HBV-positive blood; and the virus was successfully transmitted through transtadial transmission through different life stages and excreted to bed bug feces (Blow 2001). However, the virus was not transovarially transmitted to the offspring [19]. Another study found human immunodeficiency virus (HIV) was ingested into bed bug guts, but the virus was not replicated within the bed bug bodies, nor detected in bed bug feces, or mechanically transmitted into uninfected blood sources through artificial feedings [20]. Mechanical transmission of the pathogens through contaminated feces or crushing the infected bed bugs while they are still feeding is still possible, and scratching the contaminated surface of the skin might result in accidental infection [14,19]. Any hematophagous insects can potentially transmit diseases mechanically, but pathogens usually cannot survive long outside the host body [5]. The evidence of bed bugs mechanically transmitting human diseases is still lacking [4,5].

The primary reason why bed bugs do not vector nor transmit human diseases might be the lack of sylvatic (forest) cycles, in which obligatory wild-animal hosts are the reservoir of the disease pathogens [5]. All known human disease-transmitting arthropods such as ticks, lice, fleas, kissing bugs, and mosquitoes, have sylvatic cycles; and the pathogens have evolved to live and replicate within the internal physiological environment of the vector arthropod [5]. Theoretically, it is possible that some pathogens may evolve the ability to successfully replicate themselves within the bodies of bed bugs at some point in the future, since some pathogens were found to survive extended periods of time inside the insect body. However, the chance of bed bugs evolving to become a disease vector is probably slim. Bed bugs are most likely to encounter a limited number of the host individuals during the course of their life time, unlike mosquitoes and flies, because they lack wings and heavily rely on passive dispersal by hitchhiking [1–3,5]. Additionally, the common bed bug, *C. lectularius* L. and the tropical bed bug, *C. hemipterus* F., primarily feed on human host during the course of development, hence, exposure to the pathogens and dispersal of the pathogens are limited compared to that of mosquitoes, flies, fleas, ticks, etc. Bed bugs also have a strong instinct to hide in cracks and crevices, and their photophobic, nocturnal, thigmotactic behavior [2,3] may greatly limit the exposure to or the transmission of pathogens and diseases to another host. For these reasons, bed bugs are unlikely to be involved in a human disease outbreak currently or to become a human disease vector in the future.

2. Historical control methods

In the earliest record of bed bug control, found in Greek and Roman literature from 400 B.C., it was believed that bed bugs could be repelled by hanging the feet of a hare, stag, bear skin, or by setting a bowl of water under the bed [1,2]. All of these methods most probably had no effect, but it was around the 1690s–1700s that inspection by professionals was first recommended [1]. Tiffin and Son of London, formed in 1690, was the first exterminator company propagating to treat bed bugs, knowing that the careful inspection where bed bugs could be aggregating and prevention were the key to successful control [1]. In 1730, another exterminator, John Southall, published the first bed bug manual called *A Treatise of Buggs* [2], also emphasizing the importance of examination, and recommending the simplification of beds to make examination and extermination easier [1]. Southall imported Nonpareil liquor from Jamaica to control bed bugs [1,2]. This liquor may have been made with quassia wood, an insecticidal tree from the tropical region, but the formula has been lost [1]. Sassafras wood was believed to repel bed bugs, and it was used to build bed frames in North America around mid 1700s [1]. Setting up traps such as dish pans filled with kerosene or oil and planks of wood with many small holes were also used during that time [1]. Filling the wall cracks with gunpowder and setting a fire was recommended in 1777 from a handbook published as *The Complete Vermin-Killer* [21]. Pyrethrum, the extract of dried chrysanthemum flowers, also known as the Persian Insect Powder, was widely used in Europe and Asia, and in the United States the 1800s [1]. Boiling water