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A review on bed bugs: epidemiology, health effects, and surveillance activities

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Abstract

Recently there has been growing public concern and media coverage about the health consequences of bed bug bites and infestations. To capture all published reports in the literature and to provide best available epidemiological evidence in supporting public health policy decision making regarding bed bug control and management, we decided to perform a systematic review of all studies published between January 1, 1892 and October 1, 2010. The primary objective of the paper is to synthesize all existing epidemiological evidence regarding the health effects of bed bugs. In addition, we will document related surveillance activities worldwide and to present surveillance options for the province of Ontario, Canada with a discussion on the strengths and weakness of each of the options.

We searched the literature using the MEDLINE and EMBASE databases for studies of any medical and health effects that are related to bed bugs. Further more, we perused the bibliographies of these articles and of previously published narrative reviews and reports to identify pertinent papers that were not included in the databases. A total of 48 articles of the health effects of bed bug bites and infestations were identified. For surveillance activities of bed bugs, currently there is no requirement to report bed bug infestations to any public health or other government agency at any level worldwide.

As data on infestations are not systematically collected it is not possible to relate the increase in cases reported to an overall trend, but it does raise the possibility of a real increase in many parts of the world including Canada. The clinical symptoms due to exposures to bed bugs can vary among individuals. Indeed, not every one would develop a symptom after exposure to bed bugs. In rare cases, however, severe cutaneous reactions and allergic reactions may occur. For the most part, there were no data to support the potential of transmitting any infectious agent to humans by bed bugs.

To support the ongoing provincial efforts on bed bug control and management, we proposed ten options for the surveillance of bed bug infestations for the province of Ontario. These ten options are as follows:

- Collaborate with an existing self-reported bed bug registry (www.bedbugregistry.com)
- Data linkage to existing administrative databases such as medical service database and hospital discharge databases
- Government-financed bed bug registry
- Routine surveys, either a new stand-alone provincial-wide survey or being a part of an existing health survey such as RRFSS
- Surveillance based on databases provided voluntarily by pest control industry

- Surveillance based on the number of calls on bed bugs received by local public health units
- Surveillance based on the number of requests for support in relation to bed bug infestations received by Community and Social Services of Ontario
- Surveillance based on the participation of a representative sample of health care providers such as family practitioners
- Surveillance based on TeleHealth Ontario
- No formal surveillance

Executive Summary

Background

Bed bugs (*Cimex lectularius*) are blood-feeding insects that have plagued humans for thousands years (Goddard and deShazo 2009). Victims of bed bug bite have been reported to suffer from loss of sleep, psychological distress, as well as develop clinical symptoms such as skin rashes and allergic reactions (Centers for Disease Control and Prevention of U.S. 2010;Paul and Bates 2000). In recent years, there was a surge of reports bed bug infestation among the economically developed countries (Bauer-Dubau 2004;Bonnefory et al. 2008;Centers for Disease Control and Prevention of U.S. 2010;Doggett et al. 2004;Doggett 2009;Hwang et al. 2005;Lee et al. 2008;Paul and Bates 2000). Hwang and colleagues (Hwang et al. 2005) conducted a survey of public health officials and pest control companies in Toronto, Ontario. Their study showed that in the first six months of 2003 there were 15 phone complaints to public health officials about bed bugs whereas during the last six months of 2003 the number was doubled to 31. In addition, 85% of pest control companies in Toronto that provided treatments for bed bugs in 2003 reported an increase in the number of requested services related to bed bugs in 2003 than in 2002. The World Health Organization has since projected (Bonnefory et al. 2008) that bed bugs will continue to spread worldwide due to increasing international travel, the ban of using non-repellent and longer residual insecticides such as DDT, and growing insecticide resistance by bed bugs (Goddard and deShazo 2009).

Bed bugs belong to the *Cimicidae* family that feed exclusively on the blood of mammals, in particular human beings, or birds (Bonnefory et al. 2008;Heukelbach and Hengge 2009). In the absence of humans they may feed on mice, rats, chicken, and other animals (World Health Organization 2010). Bed bugs can be readily observed and identified as broadly oval, wingless, flat, and range from 1 to 7 millimeters in length. Adult bed bugs have a life span of six to 12 months and they can survive for several years without feeding on blood (Goddard and deShazo 2009;World Health Organization 2010). Bed bugs feed nearly always at night, when the hosts are inactive (Heukelbach and Hengge 2009). They sense and seek warm-blooded hosts mainly through the perception of body temperature and by detection of carbon dioxide (Ter Poorten and Prose 2005). Following emergence from their hiding places, bed bugs may migrate up to 20 feet to reach a victim (Kolb et al. 2009).

Research objectives

There has been growing public concern and media coverage about the health consequences of bed bug bites, however, research on the health and medical effects of bed bug has been limited

over the past several decades, largely due to the noted decline in the population of bed bugs in the second half of the 20th century (Centers for Disease Control and Prevention of U.S. 2010). To capture all published reports in the literature and to provide best available epidemiological evidence in supporting public health policy decision making regarding bed bug control and management, we performed a systematic review of all studies published between January 1, 1892 and October 1, 2010. The primary objective of the paper is to synthesize all existing epidemiological evidence regarding the health effects of bed bugs. In addition, we will document related surveillance activities worldwide and to present surveillance options for the province of Ontario, Canada with a discussion on the strengths and weakness of each of the options.

Methods

***Strategy for searching the literature and the selection of studies*:** We searched the literature using a strategy that is similar to the one described in Goddard and deShazo (2009). Specifically, we searched the MEDLINE and EMBASE databases for studies of any medical and health effects that are related to bed bugs. Further more, we perused the bibliographies of these articles and of previously published narrative reviews and reports to identify pertinent papers that were not included in the databases.

Evidence synthesis: We extracted the following data from each study of the health effects of bed bugs into a relational database: study design; study location; characteristics of the study subjects (animals or humans); and findings. We performed a synthesis of the epidemiologic evidence by summarizing in tabular form.

Results of the literature search: A total of 48 articles of the health effects of bed bug bites and infestations were identified **(Figure 3)**. For surveillance activities of bed bugs, currently there is no requirement to report bed bug infestations to any public health or other government agency at any level worldwide. No surveillance systems or tools that allow systematic monitoring and tracking of bed bug infestations were identified through the literature search.

Substantive results of health effects of bed bug bites and infestations

Bed bugs as vectors of human diseases: The possible role of bed bugs in transmission of human diseases has been examined in many studies (**Table 1**). It was found that of hepatitis B virus (HBV) DNA may persist for several weeks in the bodies of bed bugs, and it may be present in their feces. However, an attempt to transmit HBV to primates by infected bed bugs failed. Similarly, there were no data to support the potential of transmitting any other infectious agent such as hepatitis C virus (HCV) and human immunodeficiency virus (HIV) to humans by bed bugs.

Skin reactions to bed bug bites: In response to bed bug bites, typical clinical symptoms include a raised, inflamed, reddish wheal at each feeding site. For some individuals, such wheals may itch very intensively for several successive days (**Table 2**). In rare cases, victims may experience more complex cutaneous reactions such as pruritic bullous eruptions, urticarial papules, and plaques. Indeed, not every one would develop any clinical symptoms after first exposure to bed bugs. Subsequent multiple bites, however, may increase sensitization to bed bugs in humans.

Systemic reactions to bed bug bites and infestations: Asthmatic reaction and anaemia have been documented for some victims after bed bug bites or exposure to extracts of bed bugs (**Table 3**). More severe reactions may occur in rare cases. However, it appears that systemic reactions to bed bugs are uncommon in the general population.

Health inequality in relation to bed bug bites and infestations: Although good evidence is lacking, it is possible that economically-disadvantaged individuals may have disproportionably share a larger burden of adverse health impacts of bed bug infestations. Bed bug infestations may further reduce their access to the resources to maintain adequate health and may increase the levels of psychosocial stress.

Surveillance options for the province of Ontario (in alphabetic order) (**Table 4**)

Collaborate with an existing self-reported bed bug registry (www.bedbugregistry.com): This may include providing support on verification of self-reported cases. Strengths: low to medium cost. Weakness: participation rate is likely to be low for certain vulnerable and marginalized group.

Data linkage to existing administrative databases: This may consist of data from Ontario medical service database and hospital discharge database. Strengths: low cost and representative. Weakness: May capture cases that resulted in clinically important symptoms only and verification of true infestation may not always be possible.

Government-financed bed bug registry: a new registry based on the entire population of Ontario. Major strengths: representative and utility of assessment of spatiotemporal trends of bed bug infestations. Weakness: high cost and data may be less detailed as compared to surveys.

Provincial-wide surveys: Routine surveys (telephone or in-person interviews) based on a representative sample of the general population in the province. This can be a new stand-alone survey or a part of an existing health survey such as RRFSS. Major strengths: representative

population and availability of detailed information of individual characteristics, low cost if added to an existing survey. Weakness: prevalence data and high cost if it is a stand-alone survey.

Surveillance based on databases provided voluntarily by pest control industry: This may consist of encouraging voluntarily sharing data by pest control industry. Strengths: verification of bed bug infestation was already taken place and low cost. Weakness: No data on medical consequences and the data may not be generalizable if it is based on voluntary participation.

Surveillance based on the number of calls on bed bugs received by the local public health units: This may consist of all public health units in the province. Strengths: low cost and complete geographic coverage of the province. Weakness: increasing number of calls may occur due to media coverage and verification of true infestation may not always be possible.

Surveillance based on the number of requests for support in relation to bed bugs received by the Community and Social Services of Ontario: Strengths: low cost and complete geographic coverage of the province. Weakness: data may not be generalizable to the general population in the province and an increasing number of calls may occur due to media coverage.

Surveillance based on the participation of a representative sample of health care providers: This may consist of a representative sample of all family practitioners in the province. Strengths: low cost. Weakness: participation may be limited to those with the greatest interest or capacity and may lose participants over time.

Surveillance based on TeleHealth Ontario: This may consist of collecting bed bug related information from callers. Strength: low-to-medium cost. Weakness: May capture incidences that resulted in clinically important symptoms only and verification of true infestation may not always be possible.

No formal surveillance: This option has the lowest cost as compared to all other options. In addition, it is consistent with practice elsewhere. However, the main weakness is that it is unable to track trends. Additionally, it is unable to provide data in response to public fears and concerns.

Outline of Section Headers of Full Text:

Introduction
Methods
Strategy searching the literature and selection of studies
    Evidence synthesis
Results
    Research of the literature
    Epidemiology of bed bug infestations
    Substantive findings of health effects of bed bug bites and infestations
Discussion and Conclusions

1. Introduction

Bed bugs (*Cimex lectularius*) are blood-feeding insects that have plagued humans for thousands years (Goddard and deShazo 2009). Victims of bed bug bite have been reported to suffer from loss of sleep, psychological distress, as well as develop clinical symptoms such as skin rashes and allergic reactions (Centers for Disease Control and Prevention of U.S. 2010;Paul and Bates 2000).

During the latter half of the 20th century, this blood-feeding species was almost extinct in many economically developed countries due to the widespread use of synthetic pesticides such as DDT (Bonnefory et al. 2008). In recent years, however, there was a surge of reports of bed bug infestations among the developed countries (Bauer-Dubau 2004;Bonnefory et al. 2008;Centers for Disease Control and Prevention of U.S. 2010;Doggett et al. 2004;Doggett 2009;Hwang et al. 2005;Lee et al. 2008;Paul and Bates 2000). A survey conducted in 2010 with nearly 1,000 U.S. and international pest management companies (National Pest Management Association of U.S. 2010) showed that prior to 2000 about a quarter of survey respondents in the U.S. encountered a bed bug infestation, whereas in 2009 it increased sharply to 95 percent. In Berlin, Germany, a study (Bauer-Dubau 2004) showed that the number of reported cases was risen from seven in 1992 to 76 in 2004. Similarly, Doggett et al. (2004) reported an increase from nine to 37 bed bug samples received by a local hospital in Sydney, Australia between 2000 and 2004. Canada has not been excluded and a rise in reports of bed bug infestations has been observed. For example, Hwang and colleagues (Hwang et al. 2005) surveyed public health officials and pest control companies in Toronto, Ontario. Their study showed that in the first six months of 2003 there were 15 phone complaints to public health officials about bed bugs and during the last six months of 2003 the number was doubled to 31. In addition, 85% of pest control companies in Toronto that provided treatments for bed bugs in 2003 reported an increase in the number of requested services related to bed bugs in 2003 than in 2002. The World Health Organization has since projected (Bonnefory et al. 2008) that bed bugs will continue to spread worldwide due to increasing international travel, the ban of using non-repellent and longer residual insecticides, and growing insecticide resistance by bed bugs (Goddard and deShazo 2009).

1.1 Bed bug biology

Bed bugs belong to the *Cimicidae* family that feed exclusively on the blood of mammals, in particular human beings, or birds (Bonnefory et al. 2008;Heukelbach and Hengge 2009). In the absence of humans they may feed on mice, rats, chicken, and other animals (World Health Organization 2010).

Bed bugs can be readily observed and identified as broadly oval, wingless, flat, and range from 1 to 7 millimeters in length (**Figure 1**). The juveniles of the common bed

bugs usually have a light cream appearance, but progressively becoming reddish-brown in color (Bonnefory et al. 2008). They have two pairs of legs, a short, broad head with a pair of prominent antennae, and two dark eyes (Thomas et al. 2004). Female bed bugs are slightly smaller than males. Each female may lay between 200 and 500 cream-colored eggs in her lifetime (Bonnefory et al. 2008). It usually takes six weeks to several months for an egg to develop into a adult bed bug, depending on temperature and the availability of food (World Health Organization 2010). Adult bed bugs have a life span of six to 12 months and they can survive for several years without feeding on blood (Goddard and deShazo 2009;World Health Organization 2010).

To feed on human blood or to seek shelter, bed bugs may move from one room to another through holes in walls, water pipes, heating ducts, or gutters. However, because bed bugs have no wings, they travel only short distance. As a result, the spread of bed bugs largely depends on their human hosts, by the ways of old furniture, used mattress, and clothing (Goddard and deShazo 2009). In addition, it is speculated that migratory species of birds and bats may be a source of infestations of bed bugs (Thomas et al. 2004).

Figure 1. A photography of bed bug (Cimex lectularius), as it was in the process of ingesting a blood meal from the arm of a “voluntary” human host (Reprint with permission from CDC/ Harvard University, Drs. Gary Alpert and Harold Harlan)

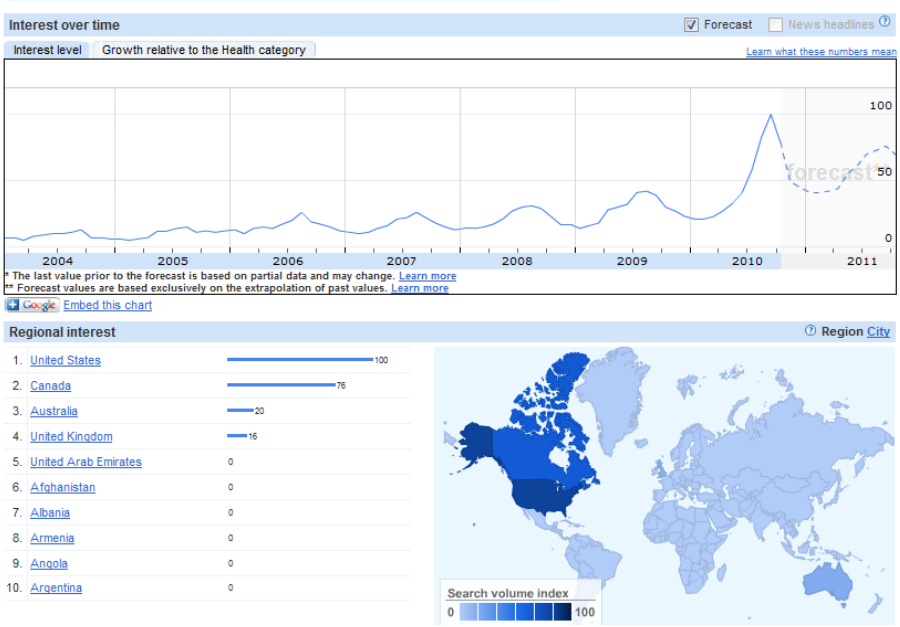
In daylight, bed bugs seek shelter in dark, dry places in beds, mattresses, cracks in walls and floors, and furniture; and they may also hide behind pictures and wallpaper (World Health Organization 2010). They feed nearly always at night, when the hosts are inactive (Heukelbach and Hengge 2009). They sense and seek warm-blooded hosts mainly through the perception of body temperature and by detection of carbon dioxide (Ter Poorten and Prose 2005). Following emergence from their hiding places, bed bugs may migrate up to 20 feet to reach a victim (Kolb et al. 2009). Feeding takes about 10–15 minutes for adult bed bugs, and is repeated about every three days (World Health Organization 2010). Bed bug bites often occur in a unique bite pattern of a linear group of three or four, sometimes referred to as a "breakfast, lunch, dinner" pattern (Thomas et al. 2004).

1.2 Research Objectives

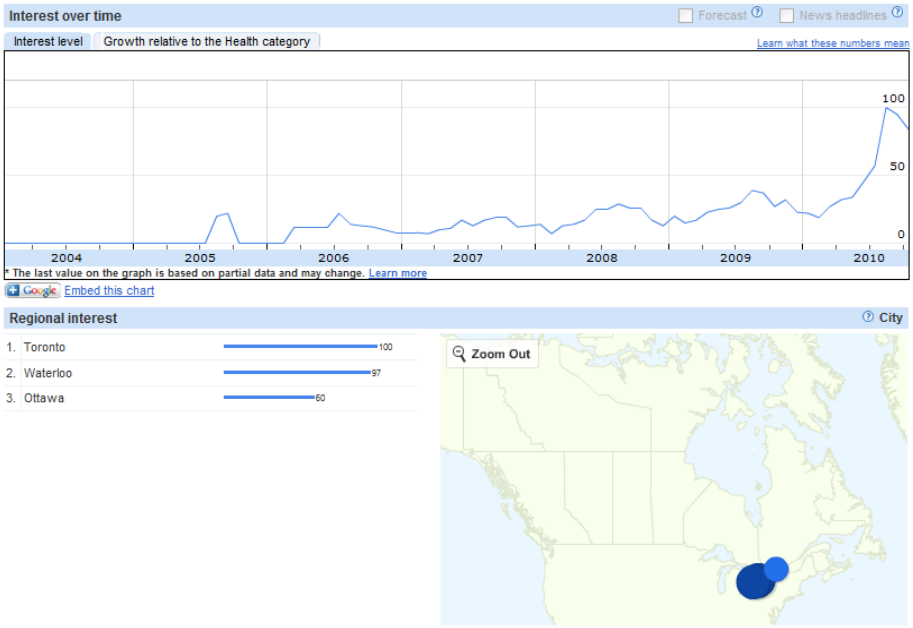
There has been growing public concern and media coverage about the health consequences of bed bug bites (**Figure 2**), however, research on the health and medical effects of bed bug has been limited

over the past several decades, largely due to the noted decline in the population of bed bugs in the second half of the 20th century (Centers for Disease Control and Prevention of U.S. 2010). Several reviews have been conducted to assess the clinical consequences and/or the control strategy (Bonnefory et al. 2008;Doggett 2009;Goddard and deShazo 2009;Heukelbach and Hengge 2009;Kolb et al. 2009;Thomas et al. 2004;World Health Organization 2010) and, for the most part, it was concluded that there were no data to support the potential of transmitting any infectious agent to humans by bed bugs. The authors of these reviews differed in their conclusions about clinical reactions by human victims to bed bug bites.

Of particular note is a systematic review that was conducted by Goddard and deShazo (2009). In this review, the authors searched thoroughly MEDLINE and EMBASE as well as by hand search of older journals, text books, and pest control trade journals. A total of 39 studies of the heath effects of bed bugs were identified and were synthesized. Indeed this study produced the most comprehensive review of the heath effects of bed bugs, however, the search of literature was limited to the articles that were published before October, 2008. In light of the continually increasing number of new studies of bed bugs each year as well as the need to provide best available epidemiological evidence in supporting public health policy decision making regarding bed bug control and management, we decided to perform an updated systematic review of all studies published between January 1, 1892 and October 1, 2010. The primary objective of the paper is to synthesize all existing epidemiological evidence regarding the health effects of bed bugs. In addition, we will document related surveillance activities worldwide and to present surveillance options for the province of Ontario, Canada with a discussion on the strengths and weakness of each of the options.



(A) Worldwide search volume of bed bugs with GOOGLE (2004-2010)



(B) Search volume of bed bugs with GOOGLE across Ontario, Canada (2004-2010)

Figure 2. Search volume patterns of health-related topics on bed bugs between 2004 and 2010 by GOOGLE users across (A) the world and (B) Ontario, Canada. This figure was produced by using GOOGLE INSIGHTS. Arguably, these results suggest that there were increasing public interests in the health aspects of bed bugs over time, and mostly from the populations in North America. In Ontario, a large volume of search was produced by residents of Toronto, Waterloo, and Ottawa. To create the figure, we used the search query as follows: ("bedbug" OR "bed bug") AND "health".

2. Methods

2.1 Strategy searching the literature and selection of studies

We searched the literature using a strategy that is similar to the one described in Goddard and deShazo (2009). Specifically, we searched the MEDLINE and EMBASE databases for studies of any medical and health effects that are related to bed bugs. Further more, we perused the bibliographies of these articles and of previously published narrative reviews and reports to identify pertinent papers that were not included in the databases. Because of the similarity of our search strategy with the previous study, we decided to include all the papers that were identified by Goddard and deShazo (2009). In addition, we perused the articles that were excluded by this previous study, from which we included the papers that met our inclusion criteria. We restricted our search to English language papers.

We searched the bibliographic databases using the key words *bed bugs or Cimex lectularius*. We combined this search with the following terms: *bite reactions*; *skin*; *cutaneous*; *infection*; *systemic reaction*; *anemia; allergic*; *allergy*; *allergen*; *asthmatic*; *psychological*; *mental*; *mental health; health equality; health inequality; social impact; social determinant; drug effects*; *surveillance*; and *cost*. We used exploded Medical Subject Headings (MeSH) terms for searching *hypersensitivity* and *psychological stress.* We included original research articles, conference abstracts, case reports, letter to the editors, and all other types of correspondences that were published in peer-reviewed journals. Similar to Goddard and deShazo (2009), we selected studies of the health and medical effects of bed bug bites using the following inclusion criteria: (1) accounts or investigations that were original; (2) evidence of bed bug infestations was convincing; and (3) clinical description of bed bug bite reactions was in sufficiently detailed so that causal relationship between bed bug bite and clinical symptoms can be reasonably inferred. We excluded studies that failed to substantiate the evidence of bed bug infestations. In addition, we excluded the reviews unless one or more new cases were described in the articles. Additionally, studies primarily concerned with other household pests, but which mentioned peripherally bed bugs, were excluded.

We included all related publications from each investigation. If identical cases of bed bug bites were reported, we included the first report of the cases. We first screened abstracts and titles and obtained the full text of those papers that may have met our eligibility criteria. A second screening was then performed to review the paper in its entirety, and the reasons for excluding the study were recorded.

For searching surveillance activities of bed bugs, we also made use of GOOGLE and GOOGLE SCHOLAR search engine. The search was for all current and previous surveillance activities worldwide. Both government and non-government websites that documented bed bug surveillance were

reviewed. Additional information was sought from the authors when necessary.

2.2 Evidence synthesis

We extracted the following data from each study of the health effects of bed bugs into a relational database: study design; study location; characteristics of the study subjects (animals or humans); and findings. We performed a synthesis of the epidemiologic evidences by summarizing in tabular form.

3. Results

3.1 Research of the literature

Of the 22 citations identified that were published between October 1, 2008 and October 1, 2010, 12 were from MEDLINE, eight were from EMBASE, and two from hand search. After reviewing the abstracts and titles, we excluded one citation, leaving 21 articles for full review (**Figure 3**). We further excluded 14 articles for the reasons listed in Figure 2. The remaining seven articles were combined with the articles that were identified by Goddard and deShazo (2009) as well as two additional articles that met eligibility criteria, resulting in a total of 48 articles of the health effects of bed bug bites and infestations.

For surveillance activities of bed bugs, we were unable to identify any systematic tracking of bed bugs that was operated by any public health or other agency worldwide. However, there was a non-government online surveillance system that documents self-reported bed bug infestations in U.S. and Canada.

3.2 Epidemiology of bed bug infestations

Bed bugs thrive in subtropical and tropic areas, but they can be found worldwide (Heukelbach and Hengge 2009;Thomas et al. 2004). In Ontario, Canada, there are an increasing number of anecdotal reports of bed bug infestations in recent years, particularly in the area of Toronto. Concurrently, the public health agency and the social service in the province have seen growing complaints and requests for service regarding bed bugs (personal communication with Jordan Tustin, OAHPP). However, the prevalence and the overall spatiotemporal trends of bed bug infestations across the province are unknown.

3.3 Substantive findings of health effects of bed bug bites and infestations

3.3.1 Bed bugs as vectors of human diseases

The possible role of bed bugs in transmission of human diseases has been the subject of many studies (Jupp et al. 1991;Jupp and Lyons 1987;Kum and Frobisher 1932;Ogston and London 1980;Silverman et al. 2001;Taylor and Morrison 2010;Webb et al. 1989;Wills et al. 1977). **Table 1** presents a summary of main findings from these identified studies. For the majority of the studies, laboratory experiments were carried out by feeding bed bugs on disease agents and the vector

competence was evaluated. In addition, five observational studies were conducted to assess the variation of levels of disease infection in communities before and after bed bug control programs were implemented. As shown in **Table 1**, there has been no proven case of an infectious agent passed on to humans either biologically or mechanistically by bed bugs.

A number of studies have been focused on the transmission of hepatitis B virus (HBV) by bed bugs (Blow et al. 2001;Jupp et al. 1991;Jupp and McElligott 1979;Ogston et al. 1979;Ogston and London 1980;Silverman et al. 2001;Taylor and Morrison 2010;Wills et al. 1977). Six of the studies (Blow et al. 2001;Jupp et al. 1991;Jupp and McElligott 1979;Ogston and London 1980;Silverman et al. 2001;Taylor and Morrison 2010) demonstrated that HBV DNA may persist for several weeks in bed bugs after feeding on an infectious meal, and it may be present in their feces. However, an attempt to transmit HBV to chimpanzees by infected bed bugs was failed (Jupp et al. 1991). Like HBV, the potential of transmitting human immunodeficiency virus (HIV) by bed bugs has been examined under lab settings (Jupp and Lyons 1987;Webb et al. 1989). Both studies observed that after bed bugs fed on HIV-infected blood, viral replication failed to occur.

Besides HBV and HIV, the transmission of other human diseases by bed bugs has been investigated. Many of these diseases, such as epidemic cerebrospinal meningitis, beriberi, pellagra, tuberculosis, influenza, sleeping sickness, epidemic typhus, malaria, and typhoid fever, were associated with bed bugs by inference, deductive reasoning, or conjecture. Therefore, studies regarding the relationship between these individual diseases and bed bugs were not included in this review.

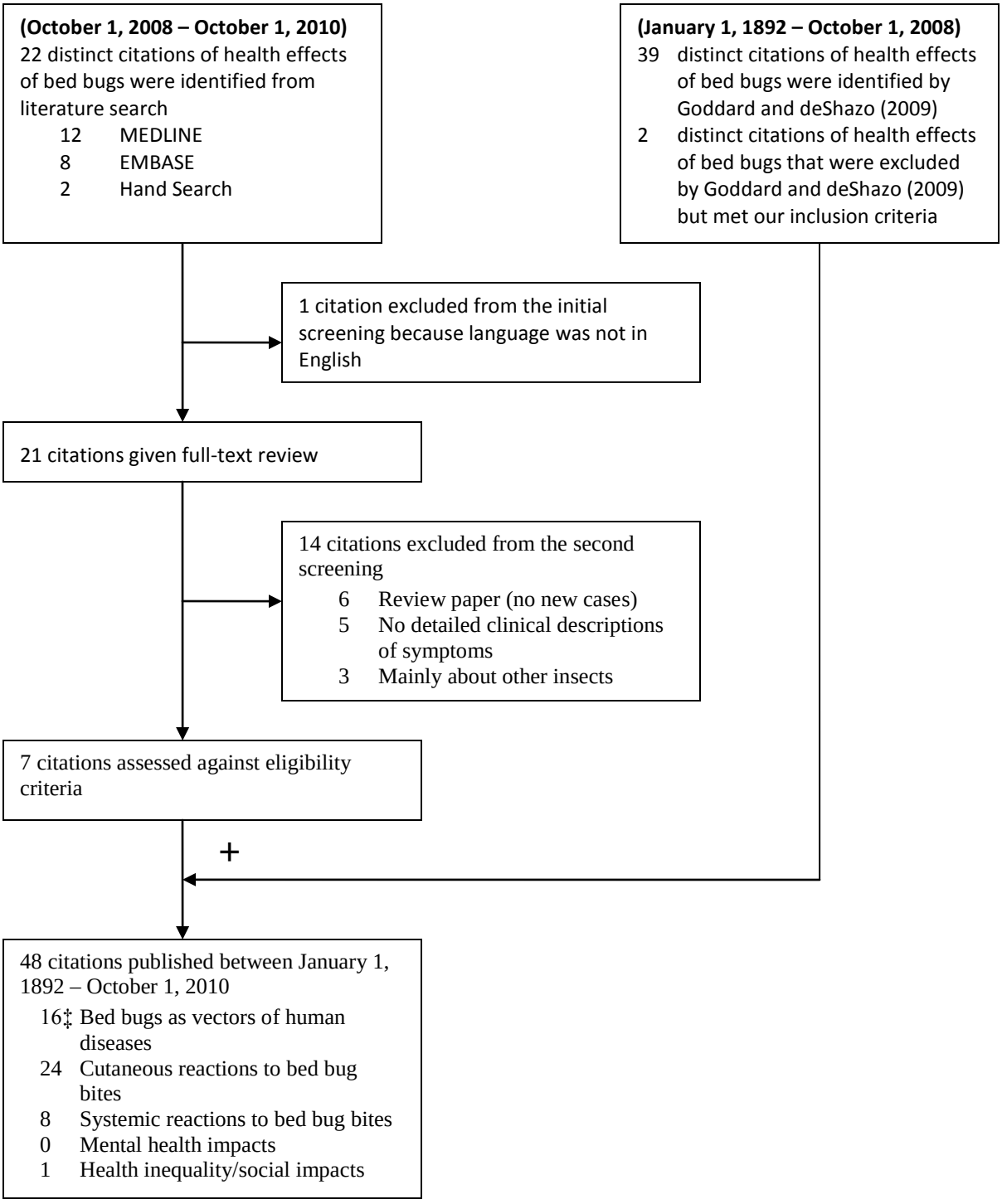


Figure 3: Flow diagram of search strategy and selection process in the systematic review of studies of health effects of bed bug bites, 1892-2010.

‡ Numbers refer to number of papers. The numbers under each category do not total 48 because multiple outcomes may have been presented in a publication.

TABLE 1. Summary of studies of bed bugs as vectors of human diseases, 1892-2010, by disease and study design †

First author, year	Type of study	Characteristics of study subject(s): Study subject	Sample size	Age	Gender	Pre-existing health conditions	Main findings
Chagas disease							
Jorg 1992	Experimental study	White lab mice	30	NA ‡	NA	NA	96.6% of white mice acquired infection with Trypanosoma cruzi through bed bugs from an infected Azara's grass mouse
Filariasis							
Nelson 1963	Experimental study	1. A human subject 2. Bed bugs	1. 1 2. 300	NA	NA	NA	Bed bugs fed on a man with infection (*Wuchereria bancrofti*), but there were no signs of development to infective stage
Hepatitis B virus (HBV)							
Ogston 1979	Experimental study	Instar nymphs	100	NA	NA	NA	No evidence of HBV replication in bed bugs
Jupp 1979	Experimental study	1. Nymphal bed bugs 2. Adult bed bugs	1. 109 2. 136	NA	NA	NA	HBsAg persisted in bed bugs for 7 weeks after experimental feeding, but no viral replication;
Ogston 1980	Experimental study	Adult bed bugs	200	NA	NA	NA	Half of the adult bed bugs were feed with HBV infected blood, HBsAg appeared in bed bug feces collected during second week of experiment and present until eighth week
Taylor 1980	Experimental study	1. Nymphal bed bugs 2. Adult bed bugs	1. 80 2. 288	NA	NA	NA	There were indications of HBV replication in bed bugs, but no transovarial transmission of HBV to bed bug offsprings
Jupp 1991	Experimental study	1. Adult bed bugs 2. Chimpanzees	1. 200 2. 3	NA	NA	NA	1. 53%-85% Of bed bugs were HBsAg-positive after feeding on infected blood via artificial membrane; 2. Attempt to artificially transmit HBV to chimpanzees failed

First author, year	Type of study	Characteristics of study subject(s)					Main findings
		Study subject	Sample size	Age	Gender	Pre-existing health conditions	
Blow 2001	Experimental study	Adult bed bugs	200	NA	NA	NA	HBV DNA was detected in the bodies of bed bugs and in their feces after infectious blood meal
Silverman 2001	Experimental study	1. Adult bed bugs 2. Human volunteers	1. 55 2. 3 cases and 3 controls	NA	NA	NA	1. Adult bed bugs fed directly on human patients and controls 2. HBV DNA persisted for long periods of time in bed bugs after feeding on an infectious meal, and was excreted in the feces
Jupp 1978	Cross sectional survey	Bed bugs in human settings	1368	NA	NA	NA	3% of bed bugs collected from huts in HBV endemic areas in Africa were found HBsAg positive
Hu 1984	Cross sectional survey	Bed bugs in human settings	401	NA	NA	NA	56.2% of bed bugs sampled from HBsAg-positive carrier's beds in China were found to be HBsAg positivity, as compared to 33.5% for bed bugs sampled from the beds human subjects with HBsAg-negative
El-Masry 1990	Cross sectional survey	Bed bugs in human settings	1800	NA	NA	NA	16% of bed bugs collected from barracks where 3.6% solders were HBsAg-positive carriers were tested HBsAg positive
Rothberg 1994	Cross sectional survey	Human subjects	641	NA	NA	NA	Treatment group had insecticide sprayed to kill bed bugs in homes over. Bed bug eradication had no effect on HBV infection rates, despite reduction in bed bugs.
Wills 1997	Cross sectional survey	Bed bugs in human settings	161	NA	NA	NA	14% of Bed bugs sampled from bedding in huts in Senegal, West Africa (HBV endemic areas), were found HBsAg-positive
Hepatitis C virus (HCV)							
Silverman 2001	Experimental study	1. Adult bed bugs 2. Human volunteers	1. NA 2. 1 case and 1 control	NA	NA	NA	HCV RNA is undetectable in bed bugs after feeding on blood from a patient with a high viral titer.

Human immunodeficiency virus (HIV)							
Jupp 1987	Experimental study	Bed bugs	100	NA	NA	NA	Artificial feeding of bed bugs of HIV infected blood failed to transmit HIV to uninfected bed bugs
Webb 1989	Experimental study	Bed bugs	115	NA	NA	NA	No viral replication in bed bugs after feeding on HIV-infected blood
Yellow fever							
Kum 1932	Experimental study	Bed bugs	20+	NA	NA	NA	Virus died so rapidly in bed bugs that disease was not transmissible to monkeys by injections of emulsified bugs later than second day after infectious meal.

† This table summarizes the findings from identified articles that were published between 1892 and 2010

‡ NA: not available

3.3.2 Skin reactions to bed bug bites

Table 2 summarizes the studies of cutaneous reactions to bed bug bites in humans. A total of 24 studies were identified. Most of the studies are case reports that described the symptoms based on one or two patients. The affected areas of the patients were usually those exposed while sleeping, for example, hands, arms, faces, necks, and legs. For the patients, their exposure to bed bugs occurred in a variety of geographic settings such as private homes, apartments, public transit, hotels, and homeless shelters (Table 2).

As shown in Table 2, the symptoms described in the case reports were usually pruritic maculopapular, erythematous lesions. Uncommon presentations have also been documented (Felton and Atkingson 2010;Fletcher et al. 2002;Leverkus et al. 2006;Liebold et al. 2003;Sansom et al. 1992). For example, Fletcher et al (2002) described a patient who developed severe widespread, pruritic bullous eruptions, urticarial papulesa, and plaques after bug bites. In another case (Leverkus et al. 2006), a patient had pruritic machules after first exposure to bed bugs, and subsequent exposures resulted in macules which then evolved into erythematous nodules with blisters.

The percentage of study population that developed skin reactions after bed bug bites varied among studies. In the study by Gbakima et al (2004), 196 of 221 refugees who were bitten by bed bugs developed wheals. In another study, Reinhardt et al (2009) showed that only 11 of 24 volunteers in their experiment had symptoms after first bites. Similarly, Ryckman and colleagues (1985) found that three of 13 volunteers developed swelling, pruritus erythma after exposure to bed bugs.

Two experimental studies were conducted to assess whether multiple exposures may increase sensitization to bed bug bites among healthy volunteers (Reinhardt et al. 2009;Usinger 1966). In the study by Usinger (1966), the author repeatedly exposed himself to bed bug bites weekly for seven years. His skin reactions progressed from delayed to immediate after multiple exposures to bed bug bites. Similarly, in the aforementioned study by Reinhardt et al (2009), it was found that after exposing to multiple bites, all volunteers including those who had no skin reaction after first bites developed symptoms of erythema, prurritus, and oedema.

3.3.3 Systemic reactions to bed bug bites and infestations

Table 3 shows a summary of eight studies of systemic reactions due to bed bug bites and infestations, five of which are case reports. Common allergic reactions such as bronchial asthma and erythema multiforme as a result of bed bug bites were reported in two studies

TABLE 2. Summary of studies of cutaneous reactions to bed bug bites, 1892-2010, by study design and year of publication †

		Characteristics of human subject(s)					
First author, year (ref)	Type of study	Study setting	Sample size	Age	Gender	Pre-existing health conditions	Main findings
Kemper 1936	Case report	Private home	1	NA ‡	NA	NA	Patient developed pruritic maculopapular, erythematous lesions
Kinnear 1948	Case report	Public transit	NA	NA	Female	NA	All patients had bullous erythema on the posterior aspects of their calves
Rook 1960	Case report	NA	1	NA	NA	NA	Patient developed papular urticaria
Sansom 1992	Case report	Hotel	2	NA	NA	NA	1. Patient one had a delayed reaction after 60 hours when pruritic papular lesions with central puncta appeared, and 4 days later, this developed into a hemorrhagic bullous rash 2. Patient two had a delayed reaction after 9 hours when a papular rash appeared
Tharakaram 1999	Case report	Hostel	1	NA	NA	NA	Patient developed erythematous pruritic rash, central puncta, bullae

First author, year (ref)	Type of study	Characteristics of human subject(s)					Main findings
		Study setting	Sample size	Age	Gender	Pre-existing health conditions	
Leverkus 2000	Case report	Hotel	1	NA	NA	NA	First exposure resulted in pruritic macules, and subsequent exposures resulted in macules which then evolved into erythematous nodules with blisters
Fletcher 2002	Case report	NA	1	NA	NA	NA	Patient developed severe widespread, pruritic, bullous eruptions, urticarial papulesa, and plaques
Liebold 2003	Case report	Hotel	1	NA	NA	NA	First exposure resulted in pruritic papulonodular reaction with bullae that became secondarily infected (impetiginization), and then subsequent exposure resulted in disseminated bullous eruption with systemic reaction (fever)
Pandey 2005	Case report	Private home	1	NA	Female	NA	Patient developed severe itchy skin rashes
Ter Poorten 2005	Case report	Private hme	1	NA	NA	NA	Patient developed erythematous papules, and then urticarial papulesa; macules, intensely pruritic
Brasch 2006	Case report	Private home	1	NA	NA	NA	Patient developed intensely pruritic papules
Masetti 2007	Case report	Private homes	2	NA	NA	NA	1. Patient one had erythema, swelling, pruritic maculae, and papulae 2. Patient two developed bullae
Goddard 2008	Case report	Hotel	1	NA	NA	NA	Patient developed erythema, pruritus, papules, puncta visible
Lee 2008	Case report	Apartment	1	30	Female	NA	Patient developed reddish itchy skin rashes
Mumcuoglu 2008	Case report	Apartment	1	NA	NA	NA	Patient developed pruritic, erythematous macules
Stucki 2008	Case report	Hotel	1	NA	NA	NA	Patient developed pruritic papules
Itamies 2009	Case report	NA	1	34	Male	NA	Patient developed erythmatous papules

First author, year (ref)	Type of study	Characteristics of human subject(s)					Main findings
		Study setting	Sample size	Age	Gender	Pre-existing health conditions	
Felton 2010	Case report	Private home	1	49	Male	NA	Patient developed intensely pruritic haemorrhagic blisters
Hwang 2005	Cross-sectional study	One selected homeless shelter	243 residents	NA	NA	NA	Of 243 residents, nine reported a skin condition consistent with bed bug bites
Gbakima 2002	Cross-sectional study	Refugee camp	221	NA	NA	NA	Of 221 refugees who were bitten by bed bugs, 196 developed wheals whereas others reported irritation, lack of sleep
Bartley 1974	Cross-sectional study	Military barracks	39	NA	NA	NA	1. 36% complained of bites 2. two sought medical aid 3. bite effects varied from none to elongate, swollen, pruritic reddish wheals
Usinger 1966	Experimental study	Lab	1	NA	Male	NA	The volunteer developed skin reactions progressed from delayed to immediate after multiple exposures
Ryckman 1985	Experimental study	Lab	14	NA	NA	NA	Three volunteers developed swelling, pruritus erythema
Reinhardt 2009	Experimental study	Lab	24	15-64	Male and female	NA	1. 11 volunteers had delayed symptoms of erythema, pruritus, oedema7-11 days after first bite; subsequent multiple bites reduced latency of skin reactions 2. 13 volunteers had no symptoms after first bites; however, subsequent multiple bites resulted in symptoms as above

† This table summarizes the findings from identified articles that were published between 1892 and 2010

‡ NA: not available

TABLE 3. Summary of studies of systemic reactions to bed bug bites and infestations, 1892-2010, by study design and year of publication †

		Characteristics of human subject(s)					
First author, year (ref)	Type of study	Study setting	Sample size	Age	Gender	Pre-existing health conditions	Main findings
Jimenez-Diaz 1935	Case report	NA	1	NA	NA	NA	Patient developed symptoms of bronchial asthma
Parsons 1955	Case report	NA	1	NA	Male	NA	Patient developed true anaphylaxis
Venkatachalam 1962	Case report	Private home	NA	<10	NA	NA	Patients developed iron deficiency anaemia
Scarupa 2006	Case report	NA	17+	NA	NA	NA	Patients developed erythema multiforme
Pritchard 2009	Case report	Private home	1	60	Male	Type 2 diabetes, hyper-cholesterolemia, reflux esophagitis, and depressions	Patient developed severe anemia as well as erythematous, excoriated papules and welts
Kemper 1929	Experimental study	Lab (intra-dermal allergy skin test)	NA	NA	NA	NA	Skin test with bed bugs showed positive
Sternberg 1929	Experimental study	Lab (intra-dermal allergy skin test)	1	NA ‡	Male	Asthmatic	Skin test with an extract from bed bugs was positive
Abou Gamra 1991	Experimental study	Lab (intra-dermal allergy skin test)	54	NA	NA	Asthmatic patients	1. 37.1% reacted positively to a common bed bug head and thorax extract 2. 50.1% reacted positively to an abdominal common bed bug extract

† This table summarizes the findings from identified articles that were published between 1892 and 2010

‡ NA: not available

(Jimenez-Diaz and Cuenca 1935;Scarupa and Economides 2006). More severe systemic reactions were also documented. For example, in one study (Pritchard and Hwang 2009), a 60-year-old man presented to his family physician with a 2-month history of fatigue and lethargy. The patient had type 2 diabetes, hypercholesterolemia, reflux esophagitis and depression. There were numerous erythematous, excoriated papules and welts on his scalp and arms. However, the patient's skin showed no visible signs of bleeding. Laboratory testing showed a hemoglobin level of 80 (normal 135–180) g/L. Four months earlier, the patient's hemoglobin level had been 147 g/L. It was found that the patient had hundreds of bed bugs in his apartment. The infestations began about 2 months before his symptom of anemia. Pest control was brought to his apartment to remove bed bugs. At six months after treatment of his apartment, the patient's anemia had not recurred. His hemoglobin level remained normal. In another study (Parsons 1955), a man experienced severe itching and urticaria on his arm and neck after bitten by bed bugs. Subsequently this patient developed true anaphylaxis with angioedema and hypotension, and was hospitalized.

Besides direct bites, exposure to allergens of bed bugs may also induce allergic reactions. For example, in the experimental study by Abou Gamra et al (1991) that included 54 asthmatic volunteers, 37.1% of them reacted positively to a common bed bug head and thorax extract. In addition, 50.1% of them reacted positively to an abdominal common bed bug extract. Similar findings were found in two earlier studies (Kemper 1929;Sternberg 1929).

3.3.4 Mental health impacts

Another potentially important health effect of bed bugs is the psychological distress caused by the bites and infestations of bed bugs. Our search of the literature, however, did not identify any published study of bed bugs on this health aspect.

3.3.5 Health inequality in relation to bed bug infestations

As shown in Table 3 and 4, bed bugs infested human dwellings in all social and economic groups. Indeed, bed bug infestations were reported to occur not only in homeless shelters and apartments, but also in private homes and public transit (**Table 3 and 4**). On the other hand, economically-disadvantaged individuals may have disproportionably share a larger burden of adverse health impacts of bed bug infestations (Lyons 2010). By interviewing with 16 inner city residents of Winnipeg, Manitoba who were victims of bed bug bites, Lyons (2010) observed that the experience of a bed bug infestation by low-income residents posed a significant threat to their overall health, and they were more likely than those of higher standing to experience social isolation, suffer from prolonged healing time and permanent

scarring, and to develop health-threatening behaviors such as smoking, alcohol abuse, poor diet, and lack of physical activity as a result of bed bug infestations.

3.4 Surveillance activities worldwide

There has not been a government financed surveillance system or tool that allows systematically monitoring and tracking bed bug infestations. City of New York, United States, was recommended by an independent bed bug advisory board to set up an integrated monitoring, tracking and reporting tool in response to bed bug infestations. However, the status of such recommended surveillance system is unclear. On the other hand, there is a non-government online bed bug registry system that documents self-reported bed bug infestations (http://www.bedbugregistry.com). It is a public database of user-submitted bed bug reports from across the United States and Canada. However, no verification of bed bug infestations is available with this bed bug registry system.

4. Discussion

4.1 Health consequences of bed bug bites and infestations

To our best knowledge, bed bugs have not been proven capable of transmitting an infectious agent to humans either biologically or mechanistically. However, there are often cutaneous or systemic reactions due to exposures to bed bugs. In response to bed bug bites, typical clinical symptoms include a raised, inflamed, reddish wheal at each feeding site. For some individuals, such wheals may itch very intensively for several successive days. In rare cases, victims may experience more complex skin reactions such as pruritic papules or nodules with blisters. Secondary bacterial infections such as impetigo, ecthyma, and cellulitis may occur after scratching (Kolb et al. 2009;Thomas et al. 2004). To a lesser degree, systemic reactions (e.g., asthmatic reaction and anaemia) have been reported for some individuals. These systemic symptoms may be induced by either bed bug bites or exposures to the extracts of bed bugs. Overall the incidence of systemic reactions to bed bugs is rare in the general population.

Jorg et al (1992) conducted a successful experimental study in which 97% of white mice acquired infection with *Trypanosoma cruzi* (which is responsible for Chagas disease) after being bitten by infected bed bugs. However, attempts to transmit *Trypanosoma cruzi* to humans by bed bugs failed in two earlier studies (Blacklock 1912;Franchini 1912). It is unclear if bed bugs are capable of transmitting this particular microorganism to humans, in particular under natural environment. Individual differences, or differences in strains of bed bugs or microorganisms, may account for any development or multiplication of the organisms in nature. Further investigations are required.

Blood feeding by bed bugs usually occurs at night and their bites are often nearly undetectable until the appearance of a clinical reaction, which can occur some days later (Doggett and Russell 2009). Indeed, not everyone bitten by bed bugs would develop a clinical reaction. Experimental studies using volunteers (Reinhardt et al. 2009;Ryckman 1985) suggested that approximately 50-70% of study population would not have any symptoms after first exposure to bed bugs. Subsequent multiple exposures, however, may increase sensitization to bed bug bites in humans (Reinhardt et al. 2009;Usinger 1966).

Apart from biomedical aspects of health consequences, the social dimension of health effects of bed bugs cannot be ignored. Indeed, those of low socioeconomic status suffer from a greater health-related impact from bed bugs than those of higher standing because they experience bed bugs differently (Lyons 2010).

The main strength of this study is that we systematically searched and synthesized all existing epidemiologic evidences regarding any health and medical effects of bed bugs in the literature. We also made efforts to identify studies that were not published in the peer-reviewed journals. The interpretation of our findings is, however, complicated by the fact that a number of incidence of bed bug bites and infestations across the world likely remain unreported due to the social stigma that associates bed bugs with the poor and dirty housing as well as the fact that there has not been any type of effective tracking and monitoring mechanism. On the other hand, the case reports identified in this review likely reported only clinically important symptoms that needed medical attention. To assess and track the scale and scope of health consequences related to bed bug bites and infestations, a systematic tracking mechanism of bed bug infestations would be needed.

4.2 Surveillance options for Ontario

Currently, there is no requirement to report bed bug infestations to any public health or other government agency at any level worldwide. Neither has there been an existing government financed surveillance system or tool that allows monitoring and tracking bed bug infestations. Indeed, establishing a surveillance system would allow us to assess the scope of the problem, identify vulnerable populations, and evaluate ongoing strategies or programs of bed bug control and management.

Bed bug infestations are a growing concern in the province of Ontario. To support public health policy decision making regarding bed bug control and management in the province, we have outlined ten possible surveillance options for the province (**Table 4**). In addition, we discussed the strengths and weaknesses of each of the surveillance options.

5. Conclusions

The issue of bed bugs represents a challenge to public health. As data on infestations are not systematically collected it is not possible to relate the increase in cases reported to an overall trend, but it does raise the possibility of a real increase in many parts of the world including Canada. The clinical symptoms due to exposures to bed bugs varied among individuals. In rare cases, severe cutaneous reactions and allergic reactions may occur. For the most part, there were no data to support the potential of transmitting any infectious agent to humans by bed bugs.

TABLE 4. Eight surveillance options for the province of Ontario in response to bed bug infestations

Option †	Brief description of surveillance option	Strengths	Weakness
1	A new, stand alone routine surveys (telephone or in-person interviews) or being a part of an existing health survey such as RRFSS	1. Representative 2. Allow establishing trends of bed bug infestations and assessing the scope of the problem	1. High cost if it is a new stand alone survey 2. Release of results may not be timely
2	Government-financed bed bug registry	1. Representative 2. Allow establishing trends of bed bug infestations and assessing the scope of the problem	1. High cost 2. Data may be less detailed or precise as compared to surveys 3. Unlikely to be complete and reporting bias may occur
3	Collaborate with an existing user-submitted bed bug registry (www.bedbugregistry.com), but provide support on verification of the reports	1. Low cost 2. Already available	1. Bed bug infestations may be under reported for certain vulnerable and marginalized groups 2. Have to accept info as currently collected
4	Surveillance based on the participation of a representative sample of health care providers, in particular family practitioners	1. Can obtain detailed information 2. Link to health outcomes	1. Participation may be limited to those with greatest interest or capacity 2. May lose participants over time 3. Expense, time required

Option †	Brief description of surveillance option	Strengths	Weakness
5	Data linkage of administrative databases, for example, medical service database and hospital discharge database	1. Low cost 2. Representative	1. Will capture only people who sought medical care 2. Verification of true infestation may not always be possible 3. Likely to miss most bites and infestations
6	Surveillance based on TeleHealth Ontario	1. Low to medium cost	1. Bed bug infestations may be under reported for certain vulnerable and marginalized groups 2. Verification of true infestation may not always be possible 3. Will capture only those who phone TeleHealth
7	Surveillance based on the number of calls on bed bugs received by the local public health units	1. Low cost 2. Complete geographic coverage of the province	1. Increasing number of calls may occur due to media coverage 2. Bed bug infestations may be under reported for certain vulnerable and marginalized groups 3. Verification of true infestation may not always be possible

Option [†]	Brief description of surveillance option	Strengths	Weakness
8	Surveillance based on the number of requests for support in relation to bed bugs received by the Community and Social Services of Ontario	1. Low cost 2. Complete geographic coverage of the province	1. Not generalizable to the general population in the province 2. Increasing number of calls may occur due to media coverage 3. Verification of true infestation may not always be possible
9	Surveillance based on databases provided voluntarily by pest control industry	1. Low cost 2. Verification of true infestation	1. Because it is voluntary action, the data may not always be generalizable 2. No data on health consequences of the victims
10	No formal surveillance	1. Lowest cost 2. Consistent with practice elsewhere	1. Unable to track trends 2. Unable to provide data in response to fears and concerns

[†] The order of options is arbitrary

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