ARTHROPOD PESTS AS DISEASE VECTORS

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Abstract - The role of biting or bloodsucking pests such as lice, bedbugs and fleas in the transmission of human pathogens is well known. The role of other arthropod pests such as cockroaches, ants and flies is less clear and whilst there is a large body of evidence that they carry a wide range of pathogenic organisms, whether they act as reservoirs or vectors of these organisms is largely unknown.

The first part of this paper deals with the biting, bloodsucking and burrowing pests that directly attack humans and gives details of the types of disease that they can transmit. These include not only diseases that are well known to be transmitted by this means (such as typhus) but also recent evidence about the role of some of these pests as possible transmitters of Hepatitis B virus, and a brief discussion of whether or not they can act as vectors of HIV.

The main part of the paper is devoted to a detailed review of the groups of organisms that are known to be carried by the other types of urban insect pests. These include viruses, bacteria, chlamydia, protozoa, fungi and helminths.

Simply finding an organism in or on an insect pest is not sufficient evidence that the pest is acting as a vector. The final part of the paper is devoted to a discussion of the evidence as to whether these pests actually transmit human pathogens.

INTRODUCTION.

The control of arthropod pests is an important part of the maintainance of hygiene and sanitation in any society. Some species of arthropods are seen as pests largely on aesthetic grounds (eg. silverfish), others because they cause either disease, uncomfortable bites, or both, and yet others because they spoil food and may also transmit disease. The belief that insect pests can act as reservoirs and vectors of infectious diseases is a major reason for taking control measures against them. This paper examines evidence as to the extent that this belief is justified.

In terms of disease transmission, arthropod pests can usefully be divided into two broad groups, "biting" (that is to say those which penetrate the human epidermis in search of food, a group which therefore includes burrowing pests such as *Sarcoptes scabei*) and "non-biting" (those which live in and around human dwellings on the products and by-products of human activity). The former may have been involved with *Homo sapiens* since that species evolved but the association of the majority of "non-biting" arthropod pests with humans probably began when people first began to live in any form of permanent dwelling, and to store food materials and other perishable items such as clothes. The close association between humans and animals brought about by domestication both increased the chance that the parasites of those animals would become those of man and, by concentrating the food, bedding and excreta of both humans and these animals, provided new and extensive sources of accommodation and food for potential pest species.

ARTHROPOD PESTS AS VECTORS OF DISEASE.

Potential human pathogens have been isolated from a wide variety of arthropod pests. However, simply finding a pathogenic micro-organism in or on a pest is not sufficient evidence that the pest is acting as a vector for that organism. Properly organised epidemiological studies are needed to prove an aetiological link. Some species of arthropods have been proved to act as disease vectors but these are largely biting types some of which are obligate parasites of man. The role of the "non-biting" arthropod pests as vectors of disease is much less clear. Most of this paper deals with the potential for these pests to act as disease vectors together with a review of evidence for the finding of disease organisms in such pests. The most important organisms themselves are discussed with a view to determining the possibility that transmission by arthropods could occur, and finally evidence as to whether transmission of pathogens from "non-biting" pests to humans actually occurs is discussed.

BITING, BLOODSUCKING, STINGING AND BURROWING PESTS

Several such pest species (which, for convenience will be given the common title "Biting Pests" in this paper) are known to be able to transmit diseases to man. These include mites, lice, fleas, ticks, flies and mosquitos which are important disease vectors in some parts of the world and which can transmit some extremely serious diseases. The role of another common biting pest, the bed bug, in the transmission of disease is less clear.

Mites

The most serious mite infestation of humans is scabies which is caused by the itch mite *Sarcoptes scabei*, a species which burrows into the skin causing a serious allergic reation. The intense irritation produced results in aggressive scratching by those affected and this may lead to secondary infections. Infestations with this parasite are generally rare where standards of hygiene are high. Scabies shows a cyclical pattern of prevalence in the United Kingdom where it is increasing at present, outbreaks having recently occurred in schools, hospitals and nursing homes (Barrett & Morse, 1993). Scabies is particularly serious in immunocompromised patients such as AIDS sufferers. *S.scabei*, whilst causing potentially serious and unpleasant infestations, does not appear to transmit infectious agents from one host to another.

Other mites which can cause problems to humans include the flour mite (*Acarus siro*) which can cause dermatitis, *Liponyssoides sanguineus* which transmits rickettsial pox (in the USA and USSR), several species of *Leptotrombidium* which, in east Asia, can transmit a rickettsial disease called scrub typhus and the harvest mite (*Trombicula autumnalis*) the bites of which can cause cause severe skin reactions.

Lice

Body lice (*Pediculus humanus* var *corporis*) are the vectors of two particularly serious diseases, typhus (*Rickettsia prowazeki*) and relapsing fever (*Borrelia recurrentis*), and of the less serious trench fever (*Rickettsia quintana*). Head lice (*P.humanus* var *capitis*) cause continuing problems throughout the world. They are a persistent problem in schools in countries such as Britain despite the development of effective insecticides. They may be able to transmit the same diseases as body lice but this is not well established. Pubic lice (*Pthirus pubis*) occur worldwide and are passed on by close bodily contact. This species may also be found on the eyelashes when hygiene is poor. Pubic lice are not known to transmit pathogens.

Wars continue to occur throughout the world and these invariably lead to an increased incidence of disease and malnutrition, and result in large numbers of refugees. The conflict in former Yugoslavia has brought this home particularly strongly to first world countries. Scabies, and head and body lice, cause serious problems in wars. They are currently rampant in the war affected areas of former Yugoslavia (WHO Health Monitor, January & May 1993) and, since typhus was endemic in that area as late as the 1970s, and since cases of Brill Zinsser's disease (recrudescent typhus) are recorded there each year, there is the real risk of an outbreak of typhus. (Relapsing fever is also endemic in former Yugoslavia). Outbreaks of typhus are best controlled by disinfestation of the human hosts by the application of insecticidal dusts as was done in Naples in 1942-3. The pyrethroid insecticides are excellent for this purpose as they have a low toxicity for man but resistance to such insecticides has recently been recorded in lice. Ironically DDT, one of the insecticides used to control the outbreak in Naples, is still one of the best for the purpose, as it is poorly absorbed through human skin and has a low toxicity for man. The need for mass disinfestation programmes is increasing as the number of countries involved in war grows. However there are at present very few insecticidal dusts on the market which are approved for this purpose, an issue which should be addressed as a matter of urgency.

Fleas

Human fleas do not generally act as important disease vectors although they are capable of transmitting plague and carry the dwarf tapeworm *Hymenolepis*, the dog tapeworm *Dipylidium caninum* and Filariid worms (Hall, 1929). It is the fleas of other animals that can be a problem to humans and, in particular, the northern rat flea (*Nosopsyllus fasciatus*) and the tropical rat flea (*Xenopsylla cheopis*) which can both act as the vector of plague (*Yersinia pestis*) and of murine typhus (*Rickettsia typhi [R.mooseri]*).

Infestations with human fleas (*Pulex irritans*) are now relatively uncommon in the United Kingdom where the majority of flea infestations at present are due to the cat flea, *Ctenocephalides felis*. Infestation with the dog flea *Ctenocephalides canis* also occurs but is less common.

Ticks

There are two families of ticks, soft ticks (Argasidae) and leather or hard ticks (Ixodidae). None is confined specifically to a human host. Soft ticks tend to feed rapidly, usually at night, and do not remain attached to their host, unlike hard ticks which feed slowly and may remain attached for several days. Ticks are capable of transmitting a very wide range of pathogens including Tick-borne encephalitis viruses, Congo-Crimean haemorrhagic fever, Lyme disease, relapsing fever, tularaemia, and a range of rickettsial diseases including Q fever, Rocky Mountain spotted fever, Boutonneuse fever and rickettsial pox (Benenson, 1990).

Flies and Mosquitos

The diptera are important vectors of disease throughout the world. The role of mosquitos as vectors of malaria and of yellow fever is well known but they also transmit dengue and many dengue-like haemorrhagic infections, filariasis, and a wide range of arboviral encephalitides (eg. eastern equine encephalitis, california encephalitis) (Benenson, 1990). These infections are, for the most part, confined to the warmer parts of the world.

Other biting fly species are also important disese vectors. In the tropics they act as vectors for diseases such as Onchocerciasis (river blindness), a filarial disease transmitted only by female flies of the genus *Simulium*, Leishmaniasis (a protozoan infection transmitted by sandflies), and sleeping sickness (trypanosomiasis) which is transmitted by tsetse flies (*Glossina* spp). In more temperate regions tularaemia can be transmitted by deer flies (*Chrysops discalis*). In the United Kingdom transmission of disease by biting dipterans is rare, infections associated with their bites being due mainly to the introduction of skin flora into the tissues (although if these infections are due to beta-haemolytic streptococci, they can be life-threatening). One biting fly which does cause problems in small areas of the southern part of the United Kingdom is the Blandford fly (*Simulium posticatum*). The bite of this insect causes serious lesions and can lead to arthritic reactions but it is not currently certain whether this is due solely to an allergic reaction or whether an infectious agent is involved (Hansford & Ladle, 1979; Healing *et al* 1988).

Stinging pests

The stings of pests such as wasps and bees are generally painful and can cause severe, sometimes life-threatening, allergic reactions in some individuals due to the injection of toxins. Such pests are not thought to transmit pathogens to man. Infections do sometimes occur in association with insect stings but these are generally due to organisms from the skin flora of the affected person.

Bedbugs

Bedbugs (*Cimex lectularius*) are apparently relatively recent arrivals in Northern Europe, the first record of them in England being in 1583 (Busvine, 1976). They are generally associated with low standards of hygiene and became increasingly common during the seventeenth and eighteenth centuries as urbanisation increased. Improved hygiene and effective insecticides have greatly reduced their numbers in most first world countries, but they remain as serious pests in areas where war or poverty inhibit hygiene.

Each of the five nymphal stages of the bed bug requires a blood meal before it proceeds to the next and they feed only on humans. They are therefore suitable candidates for consideration as vectors of disease but their role is uncertain.

The lesions left by the bites of bed bugs are often extremely irritating, due to the host's immune response and, as with other insects producing irritant bites, there is always the possibility that secondary infection may result from extensive scratching by the patient.

"NON-BITING" PESTS.

Very large numbers of different species of arthropods are found as "non-biting" pests in human premises throughout the world. In Britain alone at least 60 species are involved (Hickin, 1964). The British list includes four species of Dictyoptera (the oriental cockroach being the most common) (Baker, 1981), five of Lepidoptera, 18 species of Coleoptera, 15 of Diptera and six arachnids (Hickin, 1964). Some of these (for example silverfish and woodlice) are of little importance other than as indicators of possible damp or decay, and others, such as woodboring beetles and carpet beetles, have little direct contact with man. Such pests are often rather specific in their targets and, whilst they may be capable of causing serious allergic reactions in humans, it is the more generalist pests, particularly those which affect food and/or which are found in places such as hospitals, which are most likely to pose an important threat to the health of humans by acting as vectors of pathogens.

A few of these generalist pests (in particular, cockroaches, ants and flies) have been the subject of extensive studies, in a large part because they are found extensively in restaurants and hospitals and kitchens. Most of this review is concerned with these pests.

Cockroaches

Cockroaches are ubiquitous pests which feed on faeces, human and animal waste and on human foodstuffs. They have been found in sewers and toilets and are particularly associated with areas where food is stored or prepared. They are also common pests in hospitals and laboratories and have been known to feed on sputum and other clinical specimens. There is increasing evidence that they are capable of causing serious allergic reactions such as asthma, and that they are second only to dust mites as insect causes of these conditions (Kang & Chang, 1985; Schwartz, 1990: Brenner *et al* 1991). A wide range of species of bacteria have been shown to survive on the cuticle and in the gut (particularly the hindgut) of these insects (Bitter & Williams,1949; Roth & Willis, 1957; Burgess *et al* 1973; Bignall, 1977; Cloarec *et al* 1992) and they are therefore prime candidates to act as vectors of pathogenic organisms either mechanically or via their faeces. Burgess (1978) pointed out that there is a good correlation between the organisms in an environment and the cockroaches living in that environment, a conclusion supported by the results of many other studies (LeGuyader *et al* 1989; Fotedar *et al* 1991a,b; Cloarec *et al* 1992). For example, Cloarec and his colleagues (1992) who examined the carriage of bacteria by German cockroaches in multi-family dwellings in Rennes, France, found 30 different bacterial species in the insects. They reported that whilst the cockroaches from any one apartment all had a very similar bacterial flora, there was a very low level of overlap between the bacterial flora of cockroaches from neighbouring apartment blocks and between the flora of cockroaches from different apartments in the same block.

Ants

Several species of ants are found in buildings, the most important pest species in temperate regions being the Pharaoh's ant *Monomorium pharaonis*. Pharaoh's ants are a tropical species which, in temperate regions, have to rely on artificial heat for survival. They therefore tend to be confined to places, such as hospitals and large stores or restaurants, which are constantly heated. They are omnivorous but show a preference for raw and cooked meats and sweet items of food. They have been found in wards, kitchens and operating theatres in hospitals and visit moist areas such as bedpans, toilets, drains, sinks and sluices. Pharaoh's ants have been reported from inside sterile packs and intravenous giving sets (Rupp & Forni, 1972; Beatson 1973). They have been found feeding on discharges inside dressings of patients with suppurating lesions (Cartwright & Clifford, 1973), a behaviour which could lead to wound infection.

Flies

Many species of fly are pests (at least nine are pests in the UK) but although most of these are of no particular public health importance some species do act as carriers or vectors of pathogens. Of the non-biting flies associated with humans the most common are members of the genus *Musca* (particularly the housefly *M.domestica*). Houseflies have a strong affinity for humans and a propensity to breed in human faeces. They are also highly mobile and move readily from faecal matter and rotting animal tissue to human food or utensils. They are therefore potentially extremely important as vectors of human pathogens.

POTENTIAL PATHOGENS ISOLATED FROM ARTHROPOD PESTS.

Bacteria from the human intestinal tract

Salmonella

Salmonellas are broadly divided into those which cause enteric fever (*S.typhi* and *S.paratyphi*) and those which cause food poisoning. Enteric fever (typhoid and paratyphoid) is a serious, potentially life threatening systemic bacterial illness. Uncommon in Britain at present it is a serious cause of mortality and morbidity in the third world. The food poisoning salmonellas include a wide range of species and serotypes and this group has recently been the subject of considerable interest in the United Kingdom and elsewhere in Europe, in the Scandinavian countries, and in the United States. This has been the result of an explosive upsurge in the numbers of cases, particularly of *Salmonella enteritidis*, reported in those countries in recent years. The most commonly identified sources of *S.enteritidis* (mostly Phage Type 4 in Europe, PT8 & PT13a in the USA) are poultry and eggs, other salmonellas (eg. *S.typhimurium*) being associated with foods such as beef or milk. However, in only a small proportion of the cases of salmonella reported is a possible vehicle identified. For example in Britain only in known outbreaks of salmonellosis may a possible source be identified (and only in about 70% of outbreaks), and cases associated with known outbreaks comprise less than 10% of the total reported to the PHLS Communicable Disease Surveillance Centre in London, or the Communicable Diseases (Scotland) Unit in Glasgow each year (PHLS/SVS update).

Both enteric fever and salmonella food poisoning are transmitted by food and water contaminated with the organisms. Arthropod pests are a potential source of contamination of these items. Isolations of salmonellas from cockroaches in hospitals, or in situations where outbreaks have occurred, include the isolation of *S.typhi* from houses inhabited by typhoid patients (Antonelli, 1943), of *S.bovis-morbificans* from a small number of cockroaches in a hospital in which an outbreak caused by that organism was occurring (Mackerras & Mackerras, 1943), of *S.typhimurium* from cockroaches in a paediatric clinic in Brussels (Graffer & Merton, 1950), and of *S.typhimurium, S.bovis morbificans* and *S.oslo* from cockroaches collected in a hospital in India (Devi & Murray, 1991). The organisms isolated by Devi & Murray were all resistant to one or more antibiotics (Devi & Murray, 1991). Laboratory studies in which salmonellas have been fed to cockroaches have shown that the bacteria survive in the gut and are passed out in the faeces although they do not appear to multiply to any great extent in the insects (at least in temperate climates) (Mackerras & Pope, 1948; Olson & Rueger, 1950; Ash & Greenberg, 1980). In addition, it has been shown that salmonellas can survive for at least four years in cockroach faeces (Rueger & Olson, 1969).

Dysentery

Dysentery is a serious and important cause of morbidity (and in some areas of mortality) throughout the world. It is particularly characterised by the production of bloody diarrhoea. Although dysentery-like symptoms can result from infection with a range of organisms (eg.campylobacters) the true dysentery micro-organisms are the four species of *Shigella, S.dysenteriae, S.flexneri, S.boydii* and *S.sonnei*. In the United Kingdom infections with *S.sonnei* (which causes a relatively mild form of the disease) are the most common, followed by *S.flexneri*. Infections with the other species are much less common and are frequently associated with foreign travel.

Shigellas have been isolated from several pest species. The Shiga bacillus (*Shigella dysenteriae* type 1) was isolated from flies in the early part of this century (Manson-Bahr, 1919) and other shigella species have also been isolated from these insects in other studies (eg. Richards *et al* 1961; Bidawid *et al* 1978; Echeverria *et al* 1983). Experiments by Burgess and his colleagues (1973) showed that *S.dysenteriae* survived for about three days in the gut of oriental cockroaches (*Blatta orientalis*). Burgess and Chetwyn (1981) reported that when fifteen cases of dysentery caused by *Shigella dysenteriae* serotype 7 occurred in Northern Ireland over an eight week period, mainly among Asian food handlers working in sutler's shops, *S.dysenteriae* of the same serotype was isolated from one of ten cockroaches collected from one of the shops. The manager of this shop was the first of the fifteen cases and the isolate from the cockroach was obtained two months later.

Klebsiella

Klebsiellas are opportunist pathogens which are responsible for a wide range of infections in humans. They are an important cause of nosocomial infections, being responsible for about 10% of Gram negative infections in hospitals (Holmes & Gross, 1990). *Klebsiella pneumoniae* is often found in the respiratory tract of hospital patients and is capable of causing lower respiratory tract infections including Friedlander's pneumonia, a relatively rare pneumonia which can become chronic. Klebsiellas also cause bacteraemias, urinary tract infections and acute pyelonephritis; and are a cause of opportunistic infections in immunocompromised patients.

Numerous workers have reported the isolation of potentially pathogenic species of *Klebsiella* from cockroaches (Bitter & Williams,1949; Roth & Willis, 1957; Burgess *et al* 1973; Bignall, 1977; Cloarec *et al* 1992; Burgess,1978; LeGuyader *et al* 1989; Fotedar *et al* 1991a,b) and flies (Sramova *et al* 1991) and, in one hospital, these included multiple antibiotic resistant forms in the same proportions in which they were occurring in the patients (Fotedar *et al* 1991b).

In a study of the vector potential of houseflies (*Musca domestica*) which was undertaken in a hospital group and in a residential area in India, Fotedar and his co-workers isolated bacteria of this genus from both the cuticle and the gut of the flies. The rate of carriage was approximately the same (ca. 35%) in flies from both areas and most of the isolates were of *Klebsiella pneumoniae*. More than 80% of the isolates from flies in the hospital were resistant to four or more common antimicrobial drugs and 48% had the same resistance pattern as isolates from wounds of patients in the hospital suggesting that the flies had acquired the isolates from patients (Fotedar *et al* 1992a).

Escherichia coli

E.coli is a widespread intestinal parasite of mammals and birds. Humans are affected by a large number of serotypes, not all of which are of equal pathogenicity. The most common and important infections due to *E.coli* in humans are urinary tract infections, acute enteritis (including "travellers diarrhoea"), wound sepsis, and neonatal meningitis and septicaemia. Recently a serious condition, Haemolytic Uraemic Syndrome, has been shown to be caused by *E.coli* serotype O157,

E.coli is common in warm blooded hosts and has been isolated from arthropod pests. For example, Burgess and Chetwyn isolated three strains of *E.coli* from a large number of cockroaches from sewers, hospitals and hotels in London (Burgess & Chetwyn, 1981) and Beatson (1972) reported the isolation of *E.coli* from ants collected from kitchens, wards, washrooms and toilets in several hospitals in Britain. Sramova and co-workers isolated *E.coli* from flies collected at a health care facility in Czechoslovakia (Sramova *et al* 1991).

Cockroaches can carry the organisms for some time after contact with contaminated material. In one study, cockroaches experimentally fed *E.coli* O 119 cultures excreted the bacteria for up to 20 days (Burgess *et al* 1973).

Proteus

Widely distributed in nature, bacteria of this genus are found in decomposing animal tissue, sewage, human and animal faeces and in garden soil and on vegetables. *Proteus vulgaris* and *P.mirabilis* are both pathogenic for man, are important causes of urinary tract infection, and are often isolated from infections of wounds and burns. *Proteus* spp. have been isolated from cockroaches (Cornwell & Mendes, 1981) and from ants (Beatson, 1972) collected from wards in hospitals and from catering facilities.

Campylobacter

Campylobacters have only recently been recognised as important pathogens of man (Skirrow, 1977). The species most commonly found in man are *C.jejuni* and *C.coli* which cause acute gastro-enteritis (clinically indistinguishable from that caused by salmonellas or shigellas) and are now the most commonly reported cause of this condition in the United Kingdom (Healing *et al* 1992; Pearson & Healing, 1992). Studies of the epidemiology of campylobacters are even less complete than those of salmonellas, and the extent to which they are carried by insects is almost unknown, but *Campylobacter jejuni* was recently isolated from a small proportion (0.5%) of a sample of 690 American and Oriental cockroaches captured in domestic kitchens and near poultry houses in Vom, Nigeria (Umannabuike & Irokanulo, 1986). Three of the four isolates were made from the guts of the insects and the fourth from the outer surface. Campylobacters have also been isolated from flies in several studies (Shane *et al*, 1985; Ruble, 1986; Berndtson *et al* 1988).

Other bacterial pathogens

Tuberculosis

Tuberculosis was probably the greatest killer of all the communicable diseases in the Victorian period in the United Kingdom accounting for up to one third of all deaths due to communicable disease (Wohl, 1983). The numbers of cases reported in this country, and in first world contries generally, declined steadily from the middle of the last century but there has recently been a worrying reversal of this trend in several countries including the UK and the USA. Tuberculosis remains a serious problem in third world countries and is also showing signs of a re-emergence in former Yugoslavia as a result of the war in that region. The causative organisms are bacteria of the genus *Mycobacterium*, particularly *M.tuberculosis* but also *M.bovis*.

Tuberculosis caused by *M.tuberculosis* is usually transmitted directly from person to person by bacilli in airborne droplet nuclei produced when infected persons cough or sneeze. Direct invasion via mucous membranes or breaks in the skin can occur but this mode of transmission is rare. Bovine tuberculosis (*M.bovis*) is usually transmitted by the ingestion of contaminated milk or dairy products. In general pest species probably do not play a role in the transmission of these diseases but tubercle bacilli from fresh, moist sputum from TB patients can remain viable in the cockroach gut. Morrell (1911) allowed cockroaches to feed on fresh sputum from tuberculous patients and detected acid fast bacilli in their faeces. Other workers who performed similar experiments (with *M.tuberculosis*) not only were able to detect the organisms in the faeces of the cockroaches but also to infect guinea pigs with tuberculosis by injecting them with faecal material from the cockroaches (Macfie, 1922; Reid 1933). Mycobacteria can remain viable even in dried, heat fixed material (Allen, 1981). Recent work has shown that, under laboratory conditions, *M.tuberculosis* could be isolated from faecal pellets of cockroaches allowed to feed on heat-fixed tuberculous sputum smears and that the bacteria remained viable in the faeces for at least eight weeks (Allen, 1987).

Pseudomonas

Pseudomonads are widely distributed in soil, water, sewage and the mammalian gut. Some, such as *P.aeruginosa*, are capable of producing fluorescent pigments. They survive well in warm and moist environments of the type favoured by may pest species. *P.aeruginosa* is an important cause of hospital acquired infection. Those particularly affected are patients with serious underlying conditions (such as burns or cancers) or who are subject to some form of therapeutic procedure such as an indwelling catheter or mechanical ventilation. Other pseudomonads (eg. *P.cepacia*, *P.maltophila*) are also capable of causing infections in humans but these are rare.

Pseudomonads have been isolated from cockroaches in the hospital environment (LeGuyader *et al* 1989). *Pseudomonas aeruginosa* has been isolated from Pharaoh's ants collected from inside the protective bag around a container of sterile saline infusion in a hospital (Cartwright & Clifford, 1973). In another hospital a patient who had undergone leg surgery complained of irritation and an extensive infestation of Pharaoh's ants was found in his bed. A pseudomonad was isolated from a sample of these ants and the serious wound pathogen *Pseudomonas aeruginosa* was later isolated from ants found in the ward kitchen and from drain swabs. There had been a history of pseudomonas contamination in the ward (Beatson, 1972).

Streptococci and enterococci

Streptococci are common inhabitants of the skin and intestinal tract of man. Some are largely saprophytic and cause little if any problem to their hosts but others, such as *Streptococcus pyogenes* (group A streptococci - which cause wound infections, impetigo, erysipelas, scarlet fever, cellulitis, puerperal fever), pneumococci (*S.pneumoniae* - which can cause lobar pneumonia, otitis media and meningitis) and enterococci (including *S.faecalis*) (which can cause sub-acute bacterial endocarditis and urinary tract infections) are potentially serious pathogens.

In common with other human pathogens streptococci have been isolated from cockroaches, flies and ants in the hospital environment (Shooter & Waterworth, 1944; Beatson, 1972; Burgess *et al* 1973; Cornwell & Mendes, 1981; Chadee & Le Maitre, 1990; Fotedar *et al* 1991a).

Staphylococci

The two staphylococci of particular importance in infections of humans are *Staphylococcus aureus*, which is responsible for serious pyogenic infections and is a cause of food poisoning; and *Staphyloccus epidermidis*, normally a part of the normal skin flora, which can cause infective endocarditis and can infect artificial heart valves and sites where drains have been inserted into wounds. *S.aureus* has been isolated from cockroaches, ants and flies in hospitals (Beatson, 1972; Le Guyader *et al* 1989; Fotedar *et al* 1991a; 1992b) and other staphylococcal species from cockroaches and flies in hospital and other environments (Burgess *et al* 1973; Cornwell & Mendes, 1981; Fotedar *et al* 1991a; 1992b).

Other bacterial pathogens

A wide range of other bacteria which are capable of causing illness in humans, but which are less common than those discussed above, have been isolated from arthropod pests in hospitals and food outlets. These include *Bacillus* spp. (which can cause food poisoning) (Roth & Willis, 1957), *Clostridium perfringens* (which can cause gas gangrene and food poisoning) (Fotedar *et al*. 1992b), *Acinetobacter* (which occasionally causes infections in burns units) (Beatson, 1972; Burgess *et al* 1973) and *Serratia* spp, *Citrobacter* and *Enterobacter* spp. (which are responsible for small numbers of wound infections, septicaemias, urinary tract infections and upper respiratory tract infections) (Burgess *et al* 1973; LeGuyader *et al* 1989; Sramova *et al* 1991; Cloarec *et al* 1992). *Yersinia pestis*, the causative organism of plague, has been isolated from cockroaches (Burgess, 1984).

Viruses

Poliomyelitis

Poliovirus is an enterovirus. Following ingestion by humans the virus multiplies in the pharynx and/or the small intestine and enters the body via the lymphatic system leading to a viraemia. Most infections are minor and are characterised by fever and sore throat, but a small proportion can lead to aseptic meningitis, paralytic disease and death. The usual route of transmission is from case to case, via the faecal-oral route where sanitation is poor, but pharyngeal spread is more important where sanitation is good and during epidemics. Occasionally the virus is transmitted in milk or food and (rarely) water.

Experiments have shown that poliomyelitis virus will survive in the gut of cockroaches (Syverton *et al* 1952) and the virus has been isolated from cockroaches captured on the premises of paralytic poliomyelitis patients (Syverton *et al* 1952) but there is no satisfactory evidence that insects actually spread the disease.

Hepatitis A

Like poliomyelitis, hepatitis A is an enterovirus. The disease caused by the virus (infectious hepatitis, catarrhal jaundice) is characterised by an abrupt onset of fever, anorexia, nausea and abdominal discomfort. Jaundice follows a few days later. The disease is usually mild but a severe, disabling infection lasting months can occur. Spread is normally from person to person by the faecal-oral route. Contaminated food is frequently involved. The evidence that arthropods carry and transmit infectious hepatitis is largely circumstantial. Observations by Kirk during the Second World War led him to suggest that flies might be acting as vectors of infectious hepatitis in Egypt (Kirk, 1945). A marked reduction in the incidence of hepatitis A infection in a housing project in Los Angeles following a cockroach control programme led Tarshis (1962) to suggest that the insects might have been carrying the disease.

Other viruses

Very few data exist about the carriage of other viruses by "non-biting" arthropod pests but some experimental work has been done to test the possibility that they could act as vectors. For example, Bartzokas *et al.*(1978) reported that cockroaches fed vaccinia virus in laboratory trials were still excreting the virus five days later, and in another experiment cockroaches fed suspensions of Coxsackie virus excreted detectable amounts of the virus for up to two weeks (Fischer & Syverton, 1951).

Other pathogens

Chlamydia

Chlamydias are obligate intracellular parasites very similar to bacteria. There are two species, *C.psittaci* which is the cause of Psittacosis and is a zoonotic disease transmitted mainly by birds, and *C.trachomatis* which is the cause of a sexually transmitted disease of humans (Lymphogranuloma Venereum) and also of trachoma, a progressive infection of the cornea which can lead to blindness. Transmission is usually said to be by contact with ocular or nasopharyngeal discharges from infected persons, but evidence has been advanced that it could also be transmitted by flies (Jones *et al* 1976; Jones 1980).

Fungi

Fungal infections can be broadly divided into superficial, subcutaneous and deep-seated. Superficial fungal infections are rarely serious although they may cause discomfort. Fungi associated with deep-seated mycoses are almost always pathogenic and can result in life-threatening disease. They can also be very difficult to treat. Broad-spectrum antibiotics and the treatment of patients with immunosuppressive and cyto-toxic agents, together with the increase in patients with AIDS, have meant that fungi such as *Aspergillus fumigatus* and *Candida* species, formerly considered as of little clinical significance, are now the cause of serious and often fatal disease. Candidiasis can be transmitted by contact with secretions from affected patients and from contaminated faeces. Aspergilli occur in decaying vegetation and stored foodstuffs and are generally transmitted by the inhalation of airborne fungal conidia. Fungi which may be of medical importance have been isolated from cockroaches and houseflies. These include *Candida* spp., *Rhizopus* spp., *Mucor* spp, *Aspergillus niger*, *A.flavus* and *A.fumigatus* (Roth & Willis, 1957; Fotedar *et al* 1991a; 1992b).

Protozoa

Protozoa, like other pathogenic organisms in an environment, can potentially be carried by insect pests. *Toxoplasma gondii*, an intracellular coccidian parasite of cats, is capable of causing infections which are generally mild in healthy individuals but which can cause life threatening infections in immunocompromised patients (including AIDS patients). If a primary infection occurs early in pregnancy, it can lead to fetal death or to serious brain damage. Late in pregnancy it can lead to recurrent or chronic chorioretinitis in the infant. In one laboratory study cockroaches were allowed access to feline faeces containing infectious oocysts of *Toxoplasma gondii*. *Toxoplasma* was isolated from their digestive tracts for up to seven days later and from their faeces for up to ten days. Faeces from the cockroaches, stored at room temperature and humidity, remained infectious for mice for up to 17 days (Wallace, 1972). Experiments have also shown that flies (*Musca domestica* and *Chrysoma megacephala*) are capable of transmitting oocysts of *Toxoplasma* to human food for up to 48 hours after feeding on cat faeces containing the oocysts (Wallace, 1971).

Other protozoan parasites, including *Entamoeba histolytica*, *Entamoeba coli*, and *Endolimax nana* have been isolated from wild caught cockroaches (Fotedar *et al* 1991b; Burgess 1984).

Helminths

Hall (1929) reported that a wide range of parasitic worms was found in pest species and cockroaches have been reported carrying eggs of *Enterobius vermicularis* and *Trichuris trichiura* in food preparation areas (Sondak, 1935). The eggs of roundworms (*Ascaris lumbricoides*) and of hookworms (*Ancylostoma duodenale* and *Necator americanus*) have also been isolated from cockroaches (Burgess 1984).

ARTHROPOD PESTS AND DISEASE TRANSMISSION

"Biting" pests

The role of the "biting" pests in the transmission of a number of human pathogens (eg. typhus, relapsing fever, malaria, dengue) is well known and needs no elaboration here. There has however, recently been considerable interest in the possibility that such pests may also be capable of transmitting Hepatitis B and HIV.

Hepatitis B

Hepatitis B antigen (HBAg) has been found in mosquitos (*Culex quinquefasciatus*) (Fouche *et al* 1990) and Smith and his co-workers suggested that Hepatitis B may be able to replicate in mosquitos (*Culex pipiens*) (Smith *et al* 1972). However Brotman and his colleagues found that there was a distinct correlation between digestion of the blood meal and the disappearance of HBAg (Brotman *et al* 1973). It has been suggested that biting pests such as bedbugs could transmit the virus by mechanical means particularly if they are interrupted in the midst of a blood meal and have to seek a second host. In one experiment in which bed bugs were fed blood from a patient with acute hepatitis B, the surface antigen remained detectable in the bugs for over four weeks, even after moulting when the insects usually search for a host to provide a further blood meal (Ogston *et al* 1979). In another experiment, animals on which Hepatitis B surface antigen (HBSA) positive bed bugs were fed themselves became surface antigen positive (Jupp & McElligott, 1979). HBSA has been isolated from engorged bed bugs caught in the wild in areas where hepatitis B is endemic (Wills *et al* 1977; Jupp & McElligott, 1979) and evidence that they are capable of transmitting the infection has been advanced (Vall Mayans *et al* 1990).

HIV

The transmission of HIV by arthropod vectors is not thought to be likely. The epidemiological, entomological and virological evidence is all against such a mode of transmission (Burgess & Kajekar, 1989). Epidemiological evidence is against such a vector because, in Africa, where AIDS is more common than anywhere else, and where there are many kinds of blood sucking insects, AIDS remains a disease of adults whilst blood sucking insects attack all ages. There is currently no evidence that HIV can replicate in insects and so developmental transmission of the virus (as occurs with yellow fever) is not possible but, despite its fragility, the virus can survive for up to 10 days in the gut of some biting arthropods (Humphrey-Smith *et al* 1993). The only way in which arthropods could therefore transmit HIV is mechanically and, whilst it is known that at least three retroviruses can be transmitted mechanically by arthropod vectors (Bovine leukaemia virus, Friend murine leukaemia virus, equine infectious anaemia virus) (Foil & Issel, 1991), none of these is a virus of humans. Mechanical transmission generally requires high levels of viraemia in the vertebrate host, contamination of the mouthparts of the vector and interruption of the feeding of the vector. Levels of viraemia in humans tend to be very low, many biting species clean their mouthparts in one way or another after feeding, and interrupted feeding is not thought to be a means by which arthropods could transmit HIV (Jupp & Lyons, 1987; Webb *et al* 1989). There is no epidemiological evidence to support this route of transmission (Friedland & Klein, 1987; Lifson, 1988). Laboratory studies have suggested that transmission of HIV by another mode of mechanical transmission (regurgitation or ingestion/egestion), such as has been implicated in the transmission of plague by fleas, is also unlikely although the situation in the field may be different (Humphrey-Smith *et al* 1993).

"Non-biting" pests

The role of the "non-biting" pests as vectors of disease is, in general, far from clear. The material presented in the preceding sections indicates clearly that such pests carry a wide range of disease causing organisms but also, as Burgess has emphasised, that their microbial flora reflects that of their environment (Burgess, 1978). Are they then simply acting as an indicator of the presence of particular organisms or can they transmit them? They have the potential to act as important vectors of disease but there is a lack of studies properly designed to test this role and hence relatively little evidence to suggest that they actually do so. Simply finding an organism in a pest species is not sufficient evidence that the pest is acting as a vector for that organism. Equally it is not sufficient to show that a pest could theoretically act as a vector, it must be shown actually to do so.

Associations have been shown between the removal of a pest species shown to carry an organism and the disappearance of the organism from a human population, or the reduction of the number of cases of illness caused by that organism in that population. For example Tarshis (1962) reported a correlation between a decrease in the incidence of hepatitis A in a housing programme and the undertaking of a cockroach control programme. However (as Tarshis himself stated) such associations are not necessarily evidence of a causal link. Outbreaks of disease tend to follow a curve, peaking and then declining. If control of the pest is undertaken when the incidence of the disease has naturally entered a decline phase then a false correlation may appear. The epidemic curve should therefore be examined as a part of any such study.

Many (interlinked) factors can affect the likelyhood that an organism may be transmitted by an arthropod pest:

Temperature

The temperature of the environment is important when considering the ability of bacteria to multiply both and outside poikilothermic animals, and of the ability of these and other organisms to survive in or on a potential vector. Temperatures in the tropics may well permit the multiplication of organisms in arthropods, and/or on contaminated foodstuffs, whereas this would not occur in temperate regions. Higher temperatures may also permit arthropods to range more widely or to exist throughout the community rather than solely in specialised (warm) habitats such as hospitals. In addition to these factors, many of the nations in the warmer parts of the world have high levels of poverty and overcrowding, low levels of hygiene, and abundant insect populations. The availablity of material for transmission by pests, and the number of pests available to transmit such material, is therefore much higher in those regions. For these reasons arthropod pests are more likely to act as disease vectors throughout the community in warmer regions.

Ability to multiply

The ability of an organism to multiply in or on its vector or on an item contaminated by that vector may be crucial to the role of an arthropod as a vector of that organism. For example campylobacters have been isolated from both flies and cockroaches but the campylobacter species important in human disease are all thermophilic (that is to say they have an optimal growth temperature of 42°C and do not grow at temperatures below 30°C) which makes it unlikely that they will multiply in poikilothermic animals except under extreme conditions. In addition they are microaerophiles, growing best at reduced levels of oxygen (ca. 5%) and are extremely sensitive to dehydration. Because of these factors campylobacters rarely multiply on foodstuffs and campylobacteriosis is simply carried by food items, the dose reaching the individual being a fraction of the initial contaminating inoculum (Healing *et al* 1992). It is relatively unlikely therefore that such an organism would readily be transmitted by an insect vector. By contrast even if only small numbers of salmonellas or shigellas are transmitted to a foodstuff by a vector they multiply so readily in air at room temperatures that transmission by arthropods is a distinct possibility.

Infective dose

A pest may simply not transmit enough of the organism to cause an infection despite the fact that the organism may be detectable by laboratory methods. The infective dose of any organism for humans can be highly variable, depending on factors associated with the patient (eg. levels of stomach acid, previous infections), the source (eg. type of food) and the organism itself (eg. strain). There is therefore no such entity as a defined infective dose for any pathogenic species. Having said that it is known that, under the appropriate conditions, certain bacterial infections can be initiated by a very small number of organisms. For example, shigellosis can be caused by the ingestion of as few as 10 bacteria (Dupont *et al* 1989). Both salmonellosis and campylobacteriosis can also be caused by small numbers of organisms provided they contaminate a food which can carry them through the acid of the stomach (Robinson, 1981; Gill *et al* 1983).

Access to an appropriate vehicle

Direct transmission of pathogens from arthropods to humans could occur in the case of pest infestations of wounds (eg. by flies or ants) or by aerosolisation of insect excreta. Whilst the frequency with which these events occur is difficult to determine (fly infestation of wounds is far from rare in hot countries), they would only be suitable routes for a proportion of the organisms that pests could carry. In many instances a second vehicle of infection would be required. This, which is most likely to be food or water, could either act as a simple vector or, by permitting the amplification of the numbers of organisms, could allow transmission to occur. Once again, the finding of an organism on a pest may be irrelevant if no second vehicle is available.

Evidence for transmission

There is, in fact, very little good evidence that pathogens are transmitted by "non-biting" pests to any significant extent, particularly in temperate regions. Most is purely circumstantial. The best evidence is for shigellas. Human infection can occur following the ingestion of very small numbers of these organisms and they are readily transmitted from person to person and by infected food and fomites. There is also good evidence that they can be transmitted by flies. Much of the early evidence was circumstantial and consisted largely of observations linking seasonal peaks in the prevalence of flies and of diarrhoeal disease (Levine & Levine, 1991). Some experimental evidence to support these observations came from fly control programmes undertaken in the southern United States following the introduction of effective insecticides in the 1950s. These showed that a reduction in the prevalence of shigellosis occurred following the reduction in density of flies (Watt & Lindsay, 1948; Lindsay *et al* 1953). Much firmer evidence came from a prospective crossover intervention study recently undertaken in Israel. Cohen and his co-workers undertook fly control programmes at military bases and found that a reduction in the fly population led to a significant decrease in the number of clinic visits for shigellosis and for seroconversion for antibodies to shigellas (and also to enterotoxigenic *E.coli*) (Cohen *et al* 1991).

The need for control

The absence of hard evidence that "non-biting" pests are acting as reservoirs or vectors of human pathogens does not mean they they are not potential sources of such organisms. This, together with their potential as serious causes of allergies, means that active and aggressive control of these pests is essential. What is required, as a matter of urgency, is proper studies to determine whether they actually are acting as important vectors of disease.

SUMMARY

1) The role of "biting" pests in the transmission of pathogens is well documented.
2) There is a great deal of evidence that "non-biting" pests are capable of carrying a wide range of

pathogenic micro-organisms.

3) The microbial flora of "non-biting" pests tends to reflect that of their environment.

4) There is evidence that a few pathogens are transmitted by "non-biting" arthropod pests.

5) Finding a pathogen in or on an arthropod pest in an area where that pathogen is affecting the human population is not sufficient evidence that the pest is acting as a vector for, or reservoir of, the organism.

6) Showing, in the laboratory, that an arthropod species could act as a disease vector does not prove that it actually does so.

7) Elimination from an area occupied by a human population affected by a particular pathogen of a pest species in which that pathogen has been found, followed by a reduction or disappearance of that pathogen from the affected human population, is also not sufficient evidence that the pest was acting as the source of the pathogen.

8) Proper epidemiological studies, preferably prospective, are needed to determine the role of a pest as a vector of a pathogen.

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REFERENCES

Allen B.W. (1981) Survival of tubercle bacilli in heat fixed sputum smears. *J.Clin.Pathol.* 34:719-722.

Allen B.W. (1987) Excretion of viable tubercle bacilli by *Blatta orientalis* (the oriental cockroach) following ingestion of heat fixed sputum smears: a laboratory investigation. *Trans.R.Soc.Trop.Med.Hyg.* 81:98-99.

Antonelli G. (1943) La blatta, veocoli di malatti infecttive nei rurali. *Mutual Rurale Fasciata* 7:206-222.

Ash N.A. & Greenberg B. (1980) Vector potential of the German cockroach (Dictyoptera: Blattellidae) in dissemination of *Salmonella enteritidis* serotype *typhimurium*. *J.Med.Entomol.* 17:417-423.

Baker L. (1981) Pests in hospitals. *J.Hosp.Infect.* 2:5-9.

Barrett N.J. & Morse D.L. (1993) The resurgence of scabies. *Communicable Disease Report.* 3:R32-34

Bartzokas C.A., McCarthy K., Shakleton W.B. & Baker B.F. (1978) Observations of the effects of formaldehyde on cockroaches and their flora: I. Survival of vaccinia virus-infected cockroaches during fumigation with formaldehyde. *J.Hyg.Camb.* 80:125-129.

Beatson S.H. (1972) Pharaoh's ants as pathogen vectors in hospitals. *Lancet* i: 425-427.

Beatson S.H. (1973) Pharaoh's ants enter giving sets. *Lancet* i:606.

Benenson A.S. (ed) (1990). *Control of Communicable Diseases in Man.* Washington, American Public Health Association.

Berndtson E., Blomgren G. & Danielsson-Tham M.-L. (1988) Incidence of campylobacters on a poultry farm. Abstract 17. *Campylobacter IV* (Kaijser B, Falsen E. Eds) University of Goteborg. pp277-278.

Bidawid S.P., Edeson J.F.B., Ibrahim J. & Matossian R.M. (1978) The role of non-biting flies in the transmission of enteric pathogens (*Salmonella* species and *Shigella* species) in Beirut, Lebanon. *Ann.Trop.Med.Parasitol.* 72:117-121.

Bignall D.E. (1977) Some observations on the distribution of gut flora in the American cockroach *Periplaneta americana*. *J.Invertebr.Pathol.* 29:338-343.

Bitter R.S. & Williams O.B. (1949). Enteric organisms from the American cockroach. *J.Infect.Dis.* 85:87-90.

Brenner R.J., Barnes K.C., Helm R.M. & Williams L.W. (1991) Modernized society and allergies to arthropods. *American Entomologist* 1991; 143-155.

Brotman B., Prince A.M. & Godfrey H.R. (1973) Role of arthropods in transmission of Hepatitis-B virus in the tropics. *Lancet* i:1305-1308.

Burgess N.R.H. (1978) The cockroach as a health hazard. *Proc.Infect.Control Nurses Assoc.* pp 31-33.

Burgess N.R.H. (1984) Hospital design and cockroach control. *Trans.R.Soc.Trop.Med.Hyg.* 78:293-294.

Burgess N.R.H. & Chetwyn K.N. (1981) Association of cockroaches with an outbreak of dysentery. *Trans.R.Soc.Trop.Med.Hyg.* 75:332-333.

Burgess N.R.H. & Kakejar R.R. (1989) Arthropod transmission of AIDS? *J.RAMC.* 3:152-3.

Burgess N.R.H., McDermott S.N. & Whiting J. (1973a) Aerobic bacteria occurring in the hindgut of the cockroach *Blatta orientalis. J.Hyg.Camb.* 71:1-7.

Burgess N.R.H., McDermott S.N. & Whiting J. (1973b) Laboratory transmission of Enterobacteriaceae by the oriental cockroach, *Blatta orientalis. J.Hyg.Camb.* 71:9-14.

Busvine J.R. (1976) *Insects, hygiene and history.* Athlone Press, London.

Cartwright R.Y. & Clifford C.M. (1973) Pharaoh's ants. *Lancet* ii,1455.

Chadee D.D. & Le Maitre A. (1990) Ants: potential mechanical vectors of hospital infections in Trinidad. *Trans.R.Soc.Trop.Med.Hyg.* 84:297.

Cloarec A., Rivault C., Fontaine F. & LeGuyader A. (1992) Cockroaches as carriers of bacteria in multi-family dwellings. *Epidemiol Infect* 109:483-490.

Cohen D., Green M., Block C., Slepon R., Ambar R., Wasserman S.S. & Levine M.M. (1991). Reduction of transmission of shigellosis by control of houseflies *(Musca domestica). Lancet* 337:993-997.

Cornwell P.B. & Mendes M.F. (1981) Disease organisms carried by oriental cockroaches in relation to acceptable standards of hygiene. *Int.Pest.Control* May/June pp72-74.

Devi S.J.N. & Murray C.J. (1991) Cockroaches (*Blatta* and *Periplaneta* species) as reservoirs of drug-resisitant salmonellas. *Epidemiol Infect* 107:357-361.

Dupont H.L., Levine M.M., Hornick R.B. & Formal S.B. (1989) Inoculum size in shigellosis and implications for expected mode of transmission. *J.Infect.Dis.* 159:1126-1128.

Echeverria P., Harrison B.A., Tirapat C. & McFarland A. (1983) Flies as a source of enteric pathogens in a rural village in Thailand. *Appl.Environ. Microbiol.* 46:32-36.

Fischer R.G. & Syverton J.T. (1951) The cockroach as an experimental vector of coxsackie virus. *Am.J.Trop.Med.* 31:238-242.

Foil L.D. & Issel C.J. (1991) Transmission of retroviruses by arthropods. *Annu.Rev.Entomol.* 36:355-381.

Fotedar R., Shriniwas U.B. & Verma A. (1991a) Cockroaches (*Blattella germanica*) as carriers of micro-organisms of medical importance in hospitals. *Epidemiol Infect* 107:181-187.

Fotedar R., Shriniwas U.B., Samantray J.C., Nayar E. & Verma A. (1991b) Nosocomial infections: cockroaches as possible vectors of drug-resistant *Klebsiella. J.Hosp.Infect.* 18:155-159.

Fotedar R., Banerjee U., Samantray J.C. & Shriniwas U.B. (1992a) Vector potential of hospital houseflies with special reference to *Klebsiella* species. *Epidemiol Infect* 109:143-147.

Fotedar R., Shriniwas U.B., Singh S. & Verma AK. (1992b) The housefly (*Musca domestica*) as a carrier of pathogenic microorganisms in a hospital environment. *J.Hosp.Infect* 20:209-215.

Fouche A., Crewe R.M., Windsor I.M. & Karim S.S. (1990) Persistence of hepatitis B antigen in *Culex quinquefasciens* (Diptera: Culicidae) *J.Med.Entomol.* 27:697-700.

Friedland G.H & Klein R.S. (1987) Transmission of the human immunodeficiency virus. *N.Engl.J.Med.* 317:1125-1135.

Gill O.N., Bartlett C.L.R., Sockett P.N., Vaile M.S.B., Rowe B., Gilbert R.J. Dulake C., Murrell H.C. & Salmaso S. (1983) Outbreak of *Salmonella napoli* infection caused by contaminated chocolate bars. *Lancet* i:574-577.

Graffer M. & Merton S. (1950) Le role des blattes dans la transmission des salmonelloses. *Ann.Inst.Pasteur* 79:654-660.

Hall M.C. (1929), Arthropods as intermediate hosts of helminths. *Smithsonian Misc Colln.* 81:1-77.

Hansford R.G & Ladle M. (1979) The medical importance and behaviour of *Simulium austeni* Edwards (Diptera: Simuliidae) in England. *Bull. Entomol. Res.* 69:33-41.

Healing T.D., Greenwood M.H. & Pearson A.D. (1992) Campylobacters and enteritis. *Rev.Med.Micro* 3:159-167.

Healing T.D., Dlugolecka M.D., Morgan D.T.J. & Ladle M. (1988) The Blandford fly. *Communicable Disease Report* 1988 (26):3. Internal publication of the Public Health Laboratory Service.

Hickin N.E. (1964) *Household insect pests.* The Rentokill Library. Hutchinson, London.

Holmes B. & Gross R.J. (1990) Coliform bacteria: various other members of the enterobacteriaceae. In: *Topley & Wilson's Principles of Bacteriology, Virology and Immunity.* (Parker MT, Duerden BI. Eds). *Vol 2: Systematic bacteriology.* London: Edward Arnold.

Humphrey-Smith I., Donker G., Turzo A., Chastel C. & Schmidt-Mayerova H. (1993) Evaluation of mechanical transmission of HIV by the African soft tick *Ornithodoros moubata. AIDS* 7:341-347.

Jones B.R. (1980) Changing concepts of trachoma and its control. *Trans.opthal.Soc.UK.* 100:25-29.
Jones B.R., Darougar S., Mohsenine R. & Poirier RH. (1976) Communicable ophthalmia: the blinding scourge of the Middle East. *Br.J.Ophthalmol.* 60:492-498.
Jupp P.G. & McElligott S.E. (1979) Transmission experiments with hepatitis B surface antigen and the common bedbug (*Cimex lectularius L). S.Afr.Med.J.* 56:54-57.
Jupp P.G. & Lyons S.F. (1987) Experimental assessment of bed-bugs (*Cimex lectularius* and *Cimex hemipterus*) and mosquitos (*Aedes aegypti formosus*) as vectors of human immunodeficiency virus. *AIDS* 1:171-174.
Kang B. & Chang J.L. (1985). Allergic impact of inhaled arthropod material. *Clin. Rev. Allergy* 3:363-375.
Kirk R. (1945) Spread of infective hepatitis. *Lancet* i:80-81.
LeGuyader A., Rivault C. & Chaperon J. (1989) Microbial organisms carried by brown-banded cockroaches in relation to their spatial distribution in a hospital. *Epidemiol Infect* 102:485-492.
Levine O.S. & Levine M.M. (1991) Houseflies (*Musca domestica*) as mechanical vectors of Shigellosis. *Rev.Infect.Dis.* 13:688-696.
Lifson A.R. (1988) Do alternate modes for transmission of human immunodeficiency virus exist? *JAMA* 259:1353-1356.
Lindsay D.R., Stewart W.H. & Watt J. (1953) Effect of fly control on diarrheal disease in an area of moderate morbidity. *Public Health Reps.* 68:361-367.
Macfie J.W.S. (1922) Observations on the role of cockroaches in disease. *Ann.Trop.Med.Parasitol.* 16:441-448.
Mackerras I.M. & Pope P. (1948) Experimental *Salmonella* infections in Australian cockroaches. Aust.J.Exp.Biol.Med.Sci. 26:465-470.
Mackerras I.M. & Mackerras M.J. (1949) An epidemic of infantile gastro-enteritis in Queensland caused by *Salmonella bovis-morbificans (Basenau). J.Hyg.Camb.* 47:166-181.
Manson-Bahr P. (1919) Bacillary dysentery. *Trans.R.Soc.Trop.Med.Hyg.* 13:64-82.
Morrell C.C. (1911) The bacteriology of the cockroach. BMJ ii:1531-1532.
Ogston C.W., Wittenstein F.S., London W.T. & Millman I. (1979) Persistence of Hepatitis B surface antigen in the bedbug *Cimex hemipterus* Fabr. *J.Infect.Dis.* 140:411-414.
Olson T.A. & Rueger M.E. (1950) Experimental transmission of *Salmonella oranienberg* through cockroaches. *Public Health Rep.* 65:531-540.
Pearson A.D. & Healing T.D. (1992) The surveillance and control of campylobacter infection. *Communicable Disease Report* 2:R133-139.
Public Health Laboratory Service and State Veterinary Service (1993) *Update on salmonella infection.* Edition 15. PHLS/SVS, London.
Reid H.C. (1933). The cockroach as a possible carrier of tuberculosis. *Am.Rev.Tubercul.* 28:267-272.
Richards C.S., Jackson W.B., DeCapito T.M. & Maier P.P. (1961) Studies on rates of recovery of *Shigella* from domestic flies and from humans in south-western United States. *Am.J.Trop.Med.Hyg.* 10:44-48.
Robinson D.A. (1981) Infective dose of *Campylobacter* in milk. *BMJ* 282:1584.
Roth L.M. & Willis E.R. (1957) The medical and veterinary importance of cockroaches. *Smithsonian. miscell. Collns.* 134:1-147.
Ruble R. (1986) Flies and *Campylobacter. Am.J.Public Health* 12:1457.
Rueger M.E. & Olson T.A. (1969) Cockroaches (Blattaria) as vectors of food poisoning and food infection organisms. *J.Med.Entomol.* 6:185-189.
Rupp C.A. & Forni P. (1972) Formic IV therapy. *N.Engl.J.Med.* 286:894-895.
Schwartz H.J. (1990) Inhalent allergy to arthropods. *Clin.Rev.Allergy* 8: 3-13.
Shane S.M., Montrose M.S. & Harrington K.S. (1985) Transmission of *Campylobacter jejuni* by the housefly (*Musca domestica). Avian.Dis.* 29:384-391.
Shooter R.A. & Waterworth P.M. (1944) A note on the transmissability of haemolytic streptococcal infection by flies. *BMJ* 1944;247-248.
Skirrow M.B. (1977) Campylobacter enteritis: a 'new' disease. *BMJ* ii:9-11.
Smith J.A., Ogunba E. & Francis T.I. (1972) Transmission of Australia Au(1) antigen by *Culex* mosquitos. *Nature* 237:231-232.
Sondak V.A. (1935) Cockroaches as carriers and hosts of parasitic worms in Leningrad and its environs. *Shornik Robot. Posviashchennyi Dradtsatipiatiletiiu Nauchnoi Deiatelnosti, Professora E.N.Pavlovskago,* 1909-34, pp 316-332.

Sramova H., Daniel M., Absolonova V., Dedicova D., Jedlickova Z., Lhotova H., Petras P., & Subertova V. (1991) Epidemiological role of arthropods detectable in health facilities. *J.Hosp.Infect* 20:281-292.

Syverton J.T., Fischer R.G., Smith S.A., Dow R.P. & Schoof H.F. (1952) The cockroach as a natural extrahuman source of poliomyelitis virus. *Fed.Proc.* 11:483.

Tarshis B. (1962) The cockroach - a new suspect in the spread of infectious hepatitis. *Am.J.Trop.Med.Hyg.* 2:705-711.

Umannabuike A.C. & Irokanulo E.A. (1986) Isolation of *Campylobacter* subsp. *jejuni* from Oriental and American cockroaches caught in kitchens and poultry houses in Vom, Nigeria. *Int.J.Zoon.* 13:180-186.

Vall Mayans M., Hall AJ., Inskip HM., Chotard J., Lindsay SW., Coromina E., Mendy M., Alonso P.L. & Whittle H. (1990) Risk factors for transmission of hepatitis B virus to Gambian children. *Lancet* 336:1107-1109.

Wallace G.D. (1971) Experimental transmission of *Toxoplasma gondii* by filth-flies. *Am.J.Trop.Med.Hyg.* 20:411-413.

Wallace G.D. (1972) Experimental transmission of *Toxoplasma gondii* by cockroaches. *J.Infect.Dis.* 126:545-547.

Watt J. & Lindsay D.R. (1948) Diarrheal disease control studies. I. Effect of fly control in a high morbidity area. *Public Health Reps.* 63:1319-1334.

Webb P.A., Happ C.M., Maupin G.O., Johnson B.J., Ou C.Y. & Monarth T.P. (1989) Potential for insect transmission of HIV: experimental exposure of *Cimex hemipterus* and *Toxorrhynchites emoinensis* to human immunodeficiency virus. *J.Infect.Dis.* 160:970-977.

Wills W., Larouze B., London W.T., Millman I., Werner B.G., Ogston W., Pourtaghva M., Diallo S. & Blumberg B.S. (1977) Hepatitis B virus in bedbugs (*Cimex hemipterus*) from Senegal. *Lancet* 2:217-219.

Wohl A.S. (1983) *Endangered lives.* Methuen, London.

WHO Health Monitor for the War Affected Populations of Former Yugoslavia. No 4 (18th Jan 1993) and No 6 (14th May 1993). Zagreb, World Health Organization.