

Fleas of dog and cat: species, biology and flea-borne diseases

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Keywords

Cat,
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Summary

Ectoparasitic insects play a major role in veterinary medicine. Fleas infest man and animals and are the most frequent external parasites of companion animals worldwide. Some species are known to be vectors of zoonotic pathogens. Dogs and cats may play an important role either as reservoir of some of the pathogens or as transport vehicles for infected fleas between their natural reservoirs and human beings, thus playing a crucial step in the transmission cycle of flea-borne diseases. This article reviews relevant literature on morphology, classification, host specificity, geographical distribution, and seasonality of fleas infesting dogs and cats in order to improve their timely identification, prevention, and control.

Pulci di cane e gatto: specie, biologia e malattie ad esse associate

Parole chiave

Cane,
Gatto,
Malattie trasmesse da
pulci.

Riassunto

L'importante ruolo ricoperto in medicina veterinaria dagli ectoparassiti, in particolare dalle pulci, è indagato e riconosciuto. Le pulci, infatti, sono i parassiti che si rilevano più frequentemente sugli animali da compagnia e possono infestare anche gli uomini. I cani e i gatti possono quindi giocare un ruolo fondamentale nel ciclo di alcune malattie trasmesse da pulci, sia come ospiti, sia come veicoli che le trasportano in luoghi abitati dall'uomo. Questo articolo analizza la letteratura sulla morfologia, la classificazione, la specificità, la distribuzione geografica e la stagionalità delle pulci che infestano proprio cani e gatti, al fine di ridurre i tempi di identificazione e migliorare le misure di prevenzione e di controllo.

Introduction

Fleas have been known to infest man and animals since the Palaeocene (Alcaíno *et al.* 2002), and are the most frequent external parasites of companion animals worldwide. Many species may parasitize human beings and some are known to be carriers of zoonotic diseases. Historically, fleas are recognized as 1 of the most important ectoparasites of humans. Several species are natural vectors of important infectious diseases, like plague (Dobler and Pfeffer 2011). Domestic cats and dogs may play a crucial role as bridging hosts for fleas of different wild animals, domestic animals, and humans; as they may come into contact with different animals during their seeking behaviour and, therefore, acquire the fleas from other animals (Dobler and Pfeffer 2011,

Marrugal *et al.* 2013). For instance, the phoresy of the rabbit flea, *Spilopsyllus cuniculi*, by cats and dogs could lead to the transfer of the fleas to pet rabbits living in the same house. This flea is an important vector of myxomatosis, thus unvaccinated pet rabbits could be at risk (Bond *et al.* 2007).

Morphology and classification

Fleas belong to a highly specialized order: *Siphonaptera* or *Aphaniptera*, and are holometabolous insects. There is no agreement on the classification, especially with respect to the number of families and the included species. There are approximately 2,500 species (Durden *et al.* 2005, Medvedev 1998). Within the family Pulicidae.

the genus *Ctenocephalides* includes 13 species, identified according to morphological criteria based on the shape and structure of their genitalia and the presence and distribution of spinae, setae, and *ctenidia* on the body (Linardi and Santos 2012, Marrugalet *et al.* 2005).

Morphology

Adults

Fleas are apterous blood sucking insects, 1.5-10 mm in length. The body is laterally compressed with strongly sclerotized exoskeleton. The head is blunt and rather immobile, its occiput nearly overlaps the first segment of the torax (*pronotum*). Antennae are short, situated in lateral grooves, and are erectable in males, allowing the support of the female during copulation. Compound eyes are absent, while some species have small or large simple eyes (Berlinguer 1964).

As described by Kluge, the flea mouth apparatus is basically characterised by several appendages arisen from the head underside, as listed below:

- a long “unpaired stylet” before the mouth opening;
- long “paired conjugated stylets” just behind the mouth opening;
- “sheath”, into which all 3 stylets can be embedded;
- a pair of “wedge-shaped appendages” at sides;
- a pair of 4-segmented “palpi” in the anterior part of the “wedge-shaped appendages”, just near its base (Kluge 2002).

The bases of all the appendages are situated within a rounded concavity on the head underside.

This concavity is framed by an integral sclerotized cranium from all sides. Anteriorly, this is formed by an arcuate projected margin of clypeus and genae; posteriorly this encompasses a hypostomal bridge. Between the bases of the mouthparts, 3 movably jointed sclerites are present in the concavity in addition to membranous surface: an “unpaired sclerite” and a pair of “levers”. The “unpaired sclerite” is jointed to the “hypostomal bridge” (Kluge 2002).

The body of adult fleas has many spines or seta that allow the movement within fur or feather and are used for identification of the species of fleas. Among them we count the combs or *ctenidia*, a row of enlarged sclerotized spines on the head (*genal ctenidium*) or on the prothorax (*pronotal ctenidium*), a taxonomic feature that may be present or absent, e.g. *genal ctenidium* is always absent in fleas parasitizing birds (Dobler and Pfeffer 2011).

Fleas have 3 thoracic segments (pro, meso, and metathorax), each sustaining a pair of legs. On the thorax there are 2 pairs of respiratory stigmata and, according to the genus, the pronotal comb (Beaucournu and Launay 1990, Guiguen and Beaucournu 1979). They have strongly developed hind legs that permit them to jump up to 150 times their own body length. This behaviour is possible due to *resilin*, an elastomeric protein, which is compressed during the flexion of the coxa in the metathorax and then rapidly relaxed (Bitam *et al.* 2010).

The abdomen has 10 segments with 5 to 8 respiratory stigmata. The last 3 segments differentiate male from female and are taxonomically relevant for taxa identification. Genitalia are found at posterior end, their features are also of great importance for species identification (Manfredini 2005). The tergum of the ninth abdominal segment of the male is modified to form the claspers. The penis (*aedeagus*) is sclerotized.

The 2 most important flea species in pets, *Ctenocephalides canis* and *Ctenocephalides felis*, are usually separated according to the shape of the head, length of the first spine of the genal comb, number of bristles on the lateral metanotal area (Linardi *et al.* 2012), and the number of short stout bristles in the interval between the postmedian and apical long bristles of the dorsal margin of the hind tibia (Linardi *et al.* 2012, Linardi and Guimarães 2000).

Males can be further identified by the shape of the manubrium of the clasper (Linardi *et al.* 2012) and the size of the *hamulus* on the *aedeagus* (Beaucournu and Ménier 1998).

Eggs and larvae

Flea eggs are pearly white and approximately 0.5 mm long (Bitam *et al.* 2010, Beaucournu and Launay 1990).

Newly hatched flea larvae are slender, white, segmented, and worm-like. Legs or eyes are lacking. They are sparsely covered with short hairs and are 1-2 mm in length (first instar) or 4-5 mm length (second instar), with 3 thoracic segments and 1 abdominal segment, each of which bears a few long hairs (Soulsby 1982). They are very active hiding from light. Once the larvae have ingested adult flea faeces or other material, they become darker (Blagburn 2009). The last abdominal segment bears 2 hooked processes called the anal struts, which are used for holding onto substrata or for motion.

Pupa

The third instar larva spins a sticky cocoon gluing

dust, debris, and waste that camouflage the cocoon during metamorphosis (Dobler and Pfeffer 2011). Pupa is the resistant instar in the environment and it can survive for around 6 months waiting for a host. These shows the importance of the pre-emerged adult cat flea in the cocoon to survive unfavourable environmental conditions (Rust 2005, Rust and Dryden 1997, Silvermann *et al.* 1981)

Host specificity

Siphonaptera are rarely monoxenous at host species level, although there appear to be clades of fleas that associate with a particular host group at higher ordinal levels (Whiting *et al.* 2008.). These, however, are more habitat-than host-specific (Lewis 1993).

In general, hosts that are taxonomically related or are similar in their ecology are likely to share flea species, and thus have the potential of hosting similar pathogens (Table I). Host-specificity is important for the transmission of disease agents (Bitam *et al.* 2010).

The rodents have the most specific extant flea fauna (74%). Only 8% of fleas are known from insectivores, 5% each from marsupials and bats, and 6% of the total diversity is ornithophilic (Whiting *et al.* 2008, Bitam *et al.* 2010).

Table I. Siphonaptera families*

Family	Major host
Ancistropsyllidae	Ungulates
Ceratophyllidae	Primarily rodents, occasionally viverrids, mustelids, birds, and a single species on an insectivore (Siberian mole)
Chimaeropsyllidae	Rodents, insectivores, elephant shrews
Coptopsyllidae	Rodents (gerbils and their allies)
Ctenophthalmidae	Rodents, occasionally pikas, insectivores (shrews and moles), marsupials, and a single species on mustelids
Hystrichopsyllidae	Rodents, insectivores
Ischnopsyllidae	Bats
Leptopsyllidae	Rodents, lagomorphs (hares, rabbits, pikas), insectivores, rarely elephant shrews, and foxes
Malacopsyllidae	Edentales (armadillos)
Pulicidae (includes tungid flea)	Very broad host range, including carnivores, ungulates, bats, edentales (armadillos), and occasionally birds
Pygiopsyllidae	Rodents, marsupials, insectivores, and occasionally monotremes, birds, or 3 shrews
Rhopalopsyllidae	Primarily rodents, some on oceanic seabirds
Stephanocircidae	Rodents, a few species on marsupials
Vermipsyllidae	Carnivores and ungulates
Xiphiopsyllidae	Rodents

* Lewis 1999, Bitam *et al.* 2010.

Fleas of interest for pets, geographical distribution, and seasonality

Flea distribution extends to all continents, including Antarctica, and fleas inhabit a range of habitats and hosts from equatorial deserts, through tropical rainforests, to the arctic tundra (Dunnet and Mardon 1991). Temperature and relative humidity are factors that influence different developmental flea instars (Beck and Pfister 2004). Extreme temperatures (+35° +38°C) in combination with a relative humidity ≤ 33% profoundly reduce flea population survival (Silvermann *et al.* 1981, Silvermann and Rust 1983).

The survival of fleas during Winters in Northern temperate climates is likely to occur through several mechanism:

- the presence of adult on domestic and feral dogs and cats;
- the presence of adult on urbanized small wild animals;
- delayed development of immature instars in freeze-protected wildlife underground;
- delayed development of pupae and emergence of adults in home environment (Krasnov 2008, Rust and Dryden 1997).

The flea-infested host also needs to spend a significant amount of time in these areas, so that adult flea faeces will be deposited into the larval environment (Blagburn and Dryden 2009).

During the Summer, low moisture levels cause larval death by desiccation because immatures are extremely susceptible to heat and dryness (Silvermann *et al.* 1981, Thiemann *et al.* 2003, Blagburn and Dryden 2009). Because of this, broods occur outdoors probably only where the ground is shaded and moist (Silvermann *et al.* 1981).

There are differences in the spectrum of flea species related to geographical areas because climate might influence flea development and distribution (Beck and Pfister 2004, Comer *et al.* 2001, Comer *et al.* 2013). In Central Europe, the warm period provides the best environmental conditions for flea development (Dryden and Rust 1994, Randolph 2004)

Ctenocephalides felis

The cat flea is the most abundant ectoparasite of cats and dogs worldwide (Akucewich *et al.* 2002, Araujo *et al.* 1998, Beck *et al.* 2006, Bond *et al.* 2007, Cadiergues *et al.* 2000, Halliwell 1983, Harman *et al.* 1987, Koutinas *et al.* 1995, Rust and Dryden 1997, Visser *et al.* 2001). Several factors, including the flea's wide range of tolerance to environmental conditions, the warmer environment that is typical of buildings, climate change, and the fact that the larvae *Ctenocephalides felis* may feed on the larvae

of other flea species, may promote this species worldwide on domestic pets (Chesney 1995, Dryden and Rust 1994, Randolph 2004, Rinaldi et al. 2007).

There are 4 recognized subspecies of *C. felis* throughout the world: *Ctenocephalides felis damarensis* and *Ctenocephalides felis strongylus*, which are present primarily in East Africa, *Ctenocephalides felis orientis* that is present in India and Australia, and the widespread *Ctenocephalides felis felis* that occurs in all continents except Antarctica (Samarina 1968). The term 'cat flea', which is the approved common name for *C. felis felis*, can occasionally cause confusion (Blagburn and Dryden 2009), because this is a common parasite of dogs and cats.

***Ctenocephalides canis* (dog flea)**

Dog flea is the common name for *Ctenocephalides canis*, which may also parasitize both dogs and cats (Rust and Dryden 1997). Although it is less prevalent than *C. felis* (Kristensen et al. 1978, Rust and Dryden 1997) and very similar to *C. felis* in appearance and in biology (Bitam et al. 2010). *Ctenocephalides canis* is globally distributed (Traversa 2013).

Pulex irritans

Pulex irritans is mistakenly called the human flea, but it infests a wide variety of mammals, including dogs (Gracia et al. 2013), cats (Millan et al. 2007), and rats (He et al. 1997). *Pulex irritans* is globally distributed (Traversa 2013). It has been observed that *P. irritans* prefers to remain on dogs despite close contact with human beings. Although, this species does appear to transfer more readily among dogs and humans than *C. felis*, *C. canis*, or *Echidnophaga gallinacea* (Harman et al. 1987).

Pulex simulans

Pulex simulans is a cosmopolitan and generalist flea that parasitizes many species of mammals, especially carnivores. Female of this species cannot be distinguished by female of *P. irritans* (Amin 1966, Dittmar and Whiting 2003, Durden et al. 2005, Hopla 1980).

***Echidnophaga gallinacea* (sticktight flea)**

Echidnophaga gallinacea is called sticktight flea because of its elongated shape and is frequently found on birds (Beaucournu and Launay 1990) and only occasionally on dogs and cats in warm areas of the USA, including Florida (Harman et al. 1987, Beard et al. 1990) and Georgia (Durden et al. 2005), Egypt, Libya (Kaal et al. 2006), and Canary Islands, (Garcia et al. 2007).

***Xenopsylla cheopis* (oriental rat flea)**

Xenopsylla cheopis is called rat fleas and is the main transmitting vector of plague in the foci of human plague (Guo et al. 2000). Because of this, it is considered of great historical importance. *Xenopsylla cheopis* has been reported mainly in rodents and rarely in domestic animals (Koutinas et al. 1995). It is common in many tropical and warm temperate environments around the world (Bitam et al. 2010).

***Nosopsyllus fasciatus* (northern rat flea)**

Nosopsyllus fasciatus is a very common rat flea of temperate regions especially on *Rattus norvegicus* (Shaw et al. 2004). Occasionally it can infest pets (Visser et al. 2001).

Tunga penetrans

Tunga penetrans is unique in the realm of fleas. This is a small flea of about 1 mm in length. The female penetrates into the dermis of the host. The main hosts are humans, dogs, cats, and pigs (Linardi and Guimarães 2000, Pampiglione et al. 1998). However, *T. penetrans* parasitizes a broad range of sylvatic and domestic animals such as monkeys, elephants, armadillos, sheep, cattle, and goats (Trentini 2000).

Tunga penetrans is common in many poor communities of Latin America, the Caribbean, and sub-Saharan Africa (Ade-Serrano et al. 2001).

The following fleas, although less common, have also been reported in Europe in dogs and cats: *Archaeopsylla erinacei* (hedgehog flea), *Spilopsyllus cunicoli* (Bond et al. 2007), *Ceratophyllus gallinae* (hen flea) (Gilles et al. 2008), *Ceratophyllus garei* (that parasitizes mainly birds and abundantly occurs in their nests) (Beaucournu and Launay 1990), *Chaetopsylla globiceps* (fox flea) (Sréter and Varga 2003), *Ctenophthalmus assimilis*, *Hystrichopsylla talpae*, *Paraceras melis*, *Monopsyllus sciurorum* (Whiting et al. 2008).

Key points in flea life cycle

Flea abundance is affected by host-related, parasite-related, and environmental factors (Linardi Santos 2012).

Both adult males and females are obligate haematophagous ectoparasites (Bitam et al. 2010).

Fleas are holometabolous insects and complete a cycle from egg to adult through several larval instars and a pupal instar (Bitam et al. 2010).

The completion of the entire life cycle, from egg to adult, varies significantly among species, and details are mostly known from synanthropic flea species. The adult fleas take a blood meal and mate on host.

Generally, a blood meal is required to complete ovary development in female fleas. The female lays eggs in the fur or the surroundings of the host. Due to their spherical or oval shape, eggs roll into cracks and crevices on the floor or in near nests and bedding. Thus, flea eggs may be deposited in all those places to which domestic animals have access. The number of eggs varies in different species. *Ctenocephalides felis* can lay 40-50 eggs per day, producing approximately 1,300 eggs during the first 50 days on a host (Beaucournu and Launay 1990). Female lifetime fecundity varies among species and depends on ecological parameters. Virgin females after blood feeding produce non-viable eggs that are eaten by the larvae (Kaal *et al.* 2006). Eggs may hatch in 1 to 10 days, depending on temperature and humidity (Rothschild 1975). Larvae are free living, feeding on adult flea faeces that contain partially digested and fresh blood, which are essential for successful development. They also feed on organic debris found in the environment and on flea eggs (Blagburn and Dryden 2009, Silvermann *et al.* 1981, Thiemann *et al.* 2003). The flea-infested hosts need to spend a significant amount of time in the same areas, so that adult flea faeces and non-viable eggs will be deposited into the larval environment (Blagburn and Dryden 2009). Generally, mammals that have vast home ranges and do not inhabit dens for rearing their young, almost always do not have fleas on themselves; whereas hosts (mammals or birds) with dens or nests exhibit a more specific flea fauna (Bitam 2010). The larvae are negatively phototactic (move away from light) and positively geotactic (move toward the ground) (Lewis 1999). Therefore, indoors the larvae avoid direct sunlight and move under furniture, appliances, and among carpet fibres. Outdoors, they move into shaded areas under bushes, trees, and leaves (Coutinho and Linardi 2007, Kristensen *et al.* 1978, Zakson-Aiken *et al.* 1996). Five to 11 days are required for the larvae to moult twice, during which they grow to about 5 mm in length before developing into the pupal instar (Silvermann *et al.* 1981). Cocoons are found in soil, carpets, under furniture, and on animal bedding. At 27°C and 80% relative humidity, fleas begin to emerge approximately 5 days after pupation, and they reach peak emergence in 8 to 9 days. The pupa can remain dormant in the cocoon for several weeks, seldom this extends up to 1 year, until a suitable host arrives (quiescence) (Silvermann and Rust 1983). The pupa instar can extend the lifespan of the flea and is troublesome from a control standpoint. Other fleas may not require any stimulus for emergence (Dobler and Pfeffer 2011). Young imagoes jump to reach the host.

The adult fleas take a blood meal and mate on host. Generally, a blood meal is required to complete ovary development in female fleas. Grooming

activity of the host cause a significant reduction of eggs (Rust and Dryden 1997). When cats are allowed to groom freely, they will ingest or groom off a substantial number of fleas in a few days. When normal grooming activity of cats was restricted, an average of 85% of female and 58% of male fleas were still present on cats after 50 days (Dryden 1989). This explains the fleas increase in sick pets or in pets unable to groom.

As a result of this life cycle, adult fleas on pets represent only the tip of the iceberg. Indeed, only 1-5% of the flea population is represented by the adults on a host. The remaining 95% is hidden and is composed of immature instars present in the environment (Halos *et al.* 2014).

Flea-borne diseases

Fleas can cause discomfort to pets and their owners, skin diseases caused by fleabites, like allergic dermatitis, and anaemia.

Blood-feeding adults cause the anaemia. Females of *C. felis felis* consume up to 13.6 µl of blood per day, which is equivalent to 15 times their body weight and they are able to reach a mean weight of 0.95 mg (Dryden and Gaafar 1999, Coutinho and Linardi 2007).

Fleas are also capable of transmitting pathogens to humans (zoonoses). These ectoparasites played a historic role in human plagues and in the 'Black Death' (bubonic plague), which is estimated to have caused the deaths of a third of the world's population during the Middle Ages (Gubler 2009).

Flea allergic dermatitis (FAD)

Flea saliva contains a variety of histamine-like compounds, enzymes, polypeptides, and amino acids (Wilkerson *et al.* 2004). Biting of adult fleas is followed by a delayed reaction and skin irritation. The lesions initially appear as single or clustered in small haemorrhagic areas. A wheal forms around each bite, with a sudden peak in few minutes and, most often, the onset of itching (Traversa 2013). The lesion may become hard and papillar (Bitam *et al.* 2010, MacDonald 1993, Scheidt 1988). Dogs and cats with FAD present erythema, alopecia, excoriation, papules, crusts, itching that often lead to self-trauma, while cats show also a miliary dermatitis with alopecia, intense pruritus resulting in self-trauma caused by nibbling, licking, and scratching (Traversa 2013).

Hemoplasmas

Haemoplasmas are important epi-erythrocytic pathogens of cats that can cause haemolytic

anaemia. Severity of clinical disease ranges from subclinical infection to severe, life-threatening haemolytic crisis, depending on the species of infecting haemoplasma and other risk factors (Barrs et al. 2010). The major natural mode of transmission of haemoplasma infection in cats has not been identified yet. DNA of some haemoplasmas has been amplified from fleas on cats in several countries, suggesting that the agents are taken up during flea feeding (Lappin et al. 2006, Shaw et al. 2004).

Dipylidium caninum

Dipylidium caninum (Cyclophyllidae: Dipylidiidae) is the most prevalent tapeworm in dogs and cats and occurs world-wide (Dobler and Pfeffer 2011, Traversa 2013). Human infections have been reported in literature (Scheidt et al. 1992, Currier et al. 1973). *Dipylidium caninum* may cause disease especially in children with low hygiene standards. However, human cases are either asymptomatic or are under reported. This may be due to non-specific clinical manifestations. Animals and humans become infected by accidentally ingesting residues or whole fleas containing the infective cysticercoid (Dantas-Torres and Otranto 2014). Larval fleas ingest eggs of *D. caninum*. The eggs hatch and the hexacanth embryos infect the flea larva and develop with the flea. Once the adult flea emerges and infests a host, the hexacanth develops into an infective cysticercoid (metacystode instar) within 2-3 days. Adult *D. caninum* begins shedding proglottids within 2-3 weeks.

Acanthocheilonema reconditum

Acanthocheilonema reconditum has occasionally been reported as a zoonotic agent (Huynh et al. 2001). The vector is *C. felis*, *C. canis*, and *P. irritans*. This filarial nematode is transmitted via flea bites to dogs and human beings and is cause of subcutaneous infection in animals and ocular disease in humans (Traversa 2013, Brianti et al. 2012).

Tungiasis

Tungiasis is a parasitic skin disease widespread in poor communities in sub-Saharan Africa, South America, and the Caribbean (Feldmeier et al. 2007, Heukelbach et al. 2001, Franck et al. 2003, Heukelbach 2004). This is a zoonotic disease and in endemic areas, dogs, cats, but also rats, are commonly infested (Heukelbach et al. 2004).

Tungiasis is caused by the infestation of female fleas belonging to the genus *Tunga*. Larvae are found in several kinds of soil, although dry and sandy ground seems to be better for their development. Male and

female are haematophagous. The female enter the dermis of the host causing an intense inflammatory reaction named "neosoma" (Barnes and Radovsky 1969, Linardi 1998). There, the parasite expels hundreds of eggs and eventually die *in situ* (Pilger et al. 2008). Due to the limited jumping ability of these fleas, the most commonly affected areas are the lower extremities. Infestation with these fleas is usually limited to the feet, in the periungual region, but penetration can occur in any part of the body (Bitam et al. 2010).

The inflammatory response around burrowed fleas is the basis of the clinic-pathological manifestations. Acute inflammation – characterised by erythema, oedema, pain, and itching – is caused by the growth of the flea exerting pressure on the surrounding tissue. In the endemic areas, bacterial super-infection of the lesion is almost constant and increases the inflammatory response. Aerobic and anaerobic bacteria (including *Clostridia*) have been isolated from embedded fleas (Feldmeier and Keysers 2013, Feldmeier et al. 2002).

Rickettsial diseases

Flea-borne spotted fever (Rickettsia felis)

Rickettsia felis is an obligate intracellular Gram-negative bacterium belonging to the spotted fever group (SFG), which may cause spotted fever rickettsiosis in humans. It was first described as a human pathogen in the early 1990s (Schriefer et al. 1994) and has since been reported in patients worldwide (Bitam et al. 2010, Horta et al. 2007, Silaghi et al. 2012). *Ctenocephalides felis* is currently the only known biological vector of *R. felis*. However, molecular evidence of *R. felis* in other species of fleas as well as in ticks and mites suggests a variety of arthropod hosts (Reif and Macaluso 2009). It has been demonstrated that this flea is able to maintain a stable infected progeny through transovarial transmission (Azad et al. 1992). Cats and dogs play the role of reservoir. In humans clinical signs of the illness are similar to those of murine typhus and other febrile illnesses such as dengue.

Murine typhus (Rickettsia typhi)

Murine typhus is a worldwide zoonosis. Two cycles are involved in *R. typhi* transmission: a classical cycle rat-flea-rat and a peridomestic cycle involving cats, dogs, and their fleas (Gillespie et al. 2009). Cats and dogs have been found seropositive for *R. typhi* in both Europe and USA (Nogueras et al. 2009, Adjemian et al. 2008). The bacterium is transmitted to humans when infected flea faeces contaminate the flea feeding site or other skin abrasion (Azad

et al. 1992). It is characterised by non-specific febrile illness with symptoms of headache, arthralgia, abdominal pain, and confusion. Approximately 50% of patients also report the development of a diffuse macular or maculopapular rash, which starts on the trunk and spreads peripherally (sparing the palms and soles) nearly 1 week after the initial onset of fever and can last from 1 to 4 days. Murine typhus is often acute or mild. However, it can cause severe illness and death (Adjemian *et al.* 2008), especially if has been mistaken for other diseases because of its non-specific symptoms.

Bartonellosis

Bartonellae are emerging vector-borne pathogens that appear to be distributed in mammals worldwide (Loftis *et al.* 2006, Pennisi *et al.* 2013, Rolain *et al.* 2005).

Infections by these bacteria in humans and animals can cause various clinical symptoms ranging from a mild, flu-like illness, to more severe manifestations, such as endocarditis, myocarditis, arthritis, hepatitis, and arthralgia (Chomel *et al.* 2006). Actually 30 species belong to the genus *Bartonella* and at least 13 species or subspecies are zoonotic (Cicuttin *et al.* 2014).

Cat scratch disease (CSD) is the most common human infection caused by *Bartonella* species.

Flea faeces are the main source of infection for *Bartonella henselae* and can be inoculated by contaminated cat claws to other cats or accidentally to humans (Gil *et al.* 2013). Immunocompetent hosts, usually, can develop a primary skin lesion that starts as a vesicle at the inoculation site, 3-10 days after scratch or bite of infected cats. Regional, ipsilateral, inflammatory lymphadenopathy develops 1 to 2 weeks later in 85 to 90% of patients (Carithers 1985). Axillary, epitrochlear, neck, and jaw nodes are most frequently affected (Lamas *et al.* 2008). Nodes may be tender and have inflammatory signs (erythema, tenderness, warmth) and suppurate in 13 to 48% of cases (Carithers 1985, Daniels and McMurray 1954). Infected lymph nodes may form a pus-draining fistula through the skin. In some cases, chronic ulcerative conjunctivitis and neuroretinitis, small foci of retinitis, and angiomatous lesions, i.e. Parinaud oculoglandular syndrome, can occur (Lamas *et al.* 2008).

Flea control

Canine and feline pulicosis is characterised by high infestation rates everywhere, thus treatment and prevention are crucial in veterinary medicine.

The flea life cycle makes the flea control very hard.

As reported in section 'Life cycle', adult fleas on pets represent only 1-5% of the flea population. The remaining 95% is hidden and is composed of larvae and pupae present in the environment (Halos *et al.* 2014); while the main sources of fleas for pets are the newly emerged fleas present in the environment. Only a relatively small proportion of fleas on pets probably move from one host to infest other animals. Hence, the risk between pets sharing the same room remains low, provided that there are no immature instars in the room (Franc *et al.* 2013). For this reason, fleas are adapted to coexist with hosts that occupy nest or bedding sites.

Pupae are highly resistant and mechanically protected from the effects of insecticides (El-Gazzar *et al.* 1986).

Adults, in the absence of appropriate stimuli, may emerge from the cocoon after several months (Halos *et al.* 2014). Optimal flea control needs to take into account these life-cycle characteristics.

To eradicate flea infestations, both adult and immature instars must be eliminated and one-off methods are not effective. The most effective approach is based on so-called Integrated Pest Management (IPM), which is based on coordinated use of multiple means of control and is tailored to each context. The IPM program must target both on-host adult fleas and environmental immature instars, and be adapted to the profile, habits, and behaviour of the pet-owner and animals.

A proper flea control is based on:

- deep cleaning of the environment: regular vacuum cleaning of carpets, blankets, and pet bedding areas, so to reduce the contamination by flea eggs;
- use of appropriate anti-flea, veterinary registered products;
- choice of active ingredients or combinations with consideration of the risk for infestation or bites by other ectoparasites, such as ticks or mosquitoes;
- selection of an appropriate application technique;

When using pesticide drugs (Table II) it is crucial to consider the speed of action against infestations, long-lasting efficacy, and level of safety towards both animal and owners. In co-infestation by fleas and other parasites, a combination of formulates may be recommended to limit the number of distributions.

Some molecules, like macrocyclic lactones, act with a broad spectrum of activity, including nematodes and several arthropods. Among these drugs, topical selamectin, kills *C. felis* adults and prevents flea eggs from hatching (Traversa 2013, Iannino *et al.* 2013).

Companion animals are commonly treated with external pesticide drugs, which represent 75% of all pesticide drugs used in dogs and cats. The prevention of fleas and ticks in pets is common in the US, Europe, Australia, and Japan, and is increasing becoming more common in emerging markets such as Brazil, South Africa, and Southern Asia (Beugnet and Franc 2012). The external pesticide drugs are used through direct application on the animal and, therefore, are veterinary drugs and must undergo a registration process as veterinary medicine through health agencies in each country to obtain marketing authorization. Conversely, the insecticide, which are not applied on the animals but are used in their environment, even if they sometimes involve the same molecules, are not considered veterinary drugs but 'pesticides in the broader sense'. Their formulations (especially excipients) are usually different and the process for authorization to use differs from the one for pesticide drugs (Beugnet and Franc 2012).

Conclusions

Fleas are widely distributed throughout the world. They can cause discomfort, nuisance, allergic reactions, anaemia. They may also transmit several pathogens, some of which have public health-related implications. In Europe, the most common flea of dog and cat are *Ctenocephalides felis*. Many other species have been recorded and climate change could lead new geographic distributions of flea and flea-borne diseases.

The incidence of flea-borne diseases is much greater than is generally recognized by physicians and veterinary practitioners, consequently it is essential to pay more attention to this issue. Optimal flea control needs to take into account the flea biology and life-cycle characteristics. Adult fleas must be eliminated and further infestations by latent environmental stages should be prevented. The

Table II. List of the major pesticides used on dogs and cats.

Chemical group	Name
Insecticidal groups	
Avermectines/Milbemycines macrocyclic lactones	Moxidectin
Avermectines/Milbemycines macrocyclic lactones	Selamectin
Avermectines/Milbemycines macrocyclic lactones	Milbemycin oxime
Carbamates	Carbaryl
Chloronicotinyl-nitroguanidines, neonicotinoids	Imidacloprid
Chloronicotinyl-nitroguanidines, neonicotinoids	Dinotefuran
Chloronicotinyl-nitroguanidines, neonicotinoids	Nitenpyram
Cyclodiene Organochlorines	Lindane
Formamidines	Amitraz
Organophosphates	Diazinon
Organophosphates	Fenthion
Oxadiazine	Indoxacarb
Phenylpyrazoles	Fipronil
Phenylpyrazoles	Pyriprole
Pyrethroids	Permethrin
Pyrethroids	Deltamethrin
Pyrethroids	Flumethrin
Semicarbazone	Metaflumizone
Spinosyns macrocyclic lactones	Spinosad (Spinosyn A, Spinosyn D)
Spinosyns macrocyclic lactones	Spinetoram
IGR (Insect Growth Regulator)	
Juvenile hormon analogues	Methoprene and S-methoprene
Juvenile hormon analogues	Pyriproxyfen
Organofluorines - Benzoylureas	Lufenuron
Organofluorines - Benzoylureas	Lufenuron

most effective approach is based on IPM, which is built on coordinated use of multiple means of control and tailored to specific context.

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