# Biology, Treatment, and Control of Flea and Tick Infestations

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**KEYWORDS**

• Flea • Tick • Biology • Treatment • Control • Disease

Flea and tick infestations of pets and the home environment are a common occurrence and their elimination can be an expensive and time-consuming problem. Many problems in control can be related to a lack of understanding of parasite biology and ecology. In fact many advances in control of fleas can be directly linked to advances in our knowledge of the intricacies of flea host associations, reproduction, and survival in the premises. Understanding tick biology and ecology is far more difficult than with fleas, because North America can have up to nine different tick species infesting cats and dogs compared to one primary flea species. The range and local density of certain tick species has increased in many areas because of changes in climate, vegetation, agricultural practices, wildlife host abundance, acaricide usage, and probably several other factors. Whatever the reason, tick infestation pressure may be much higher and associated tick-transmitted diseases may be more prevalent in some locations today than in the past.

## FLEA OVERVIEW

Flea infestations are probably the most common ectoparasitic affliction of dogs and cats in North America. Although more than 2200 species and subspecies of fleas are known throughout the world, only *Ctenocephalides felis felis* (cat flea), *Ctenocephalides canis* (dog flea), *Pulex simulans,* and *Echidnophaga gallinacea* (poultry sticktight flea) occur in large numbers on dogs and cats with enough regularity to be of importance as nuisance pests.[1,2] In North America, the most commonly encountered flea species on dogs and cats is *C f felis* (**Fig. 1**).[1,2]

The term "cat flea," which is the approved common name for *C f felis*, can occasionally cause confusion. When it appears in print, it refers to the specific flea genus and

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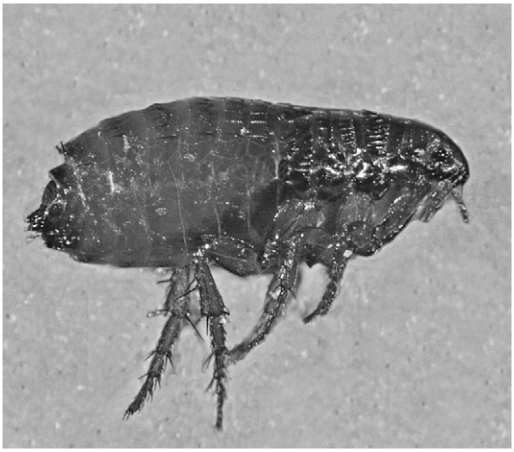

**Fig. 1.** Adult female cat flea (*C felis*).

species and not to fleas recovered from cats. There are four recognized subspecies of *C felis* throughout the world: *Ctenocephalides felis damarensis* and *C felis strongylus* occur primarily in East Africa, *C felis orientis* occurs in India and Australia, and the widespread *C f felis* occurs in all continents except Antarctica and is the only subspecies that occurs in North America.[2] Therefore, most of the North American literature refers to the cat flea as *C felis*. Because the cat flea is the most common flea on domestic dogs and cats in North America and has been extensively investigated, the following discussions on flea biology will be confined to the cat flea.

The cat flea, *C felis,* is a clinically important parasite of domestic pets, being responsible for the production of allergic dermatitis, serving as the vector of various bacterial pathogens, and being the intermediate host for filarid and cestode parasites.

Flea allergy dermatitis (see later discussion for detail) is the most common dermatologic disease of dogs and a major cause of feline miliary dermatitis.[1,2] It is an immunologic disease in which a hypersensitive state is produced in a host, resulting from the injection of antigenic material from the salivary glands of fleas. Blood consumption by fleas can produce iron deficiency anemia and even death in heavy infestations.[1,2] *Ctenocephalides felis* has also been recently implicated in the transmission of *Rickettsia typhi, Rickettsia felis*, *Bartonella henselae* and other *Bartonella spp, Mycoplasma haemofelis,* and in rare cases, even *Yersinia pestis*.[3–6] *Ctenocephalides felis* also serves as an intermediate host of the nonpathogenic subcutaneous filarid nematode of dogs, *Acanthocheilonema* (*Dipetalonema) reconditum*. Several species of cestodes can also be carried by *C felis*, including *Dipylidium caninum* and *Hymenolepis nana*.[1,2]

## FLEA BIOLOGY

Flea eggs are pearly white and oval, with rounded ends, and are 0.5 mm in length. Eggs will usually hatch in 1 to 10 days, depending on temperature and humidity.[7,8] Newly hatched flea larvae are slender, white, segmented, sparsely covered with short hairs, and 2 to 5 mm in length; they possess a pair of anal struts (**Fig. 2**). Larvae are free living, feeding on adult flea feces (which are essential for successful development), on organic debris that is found in their environment, and on flea eggs.[1,2] Once the larvae have ingested adult flea feces or other material, they become darker. Flea larvae avoid

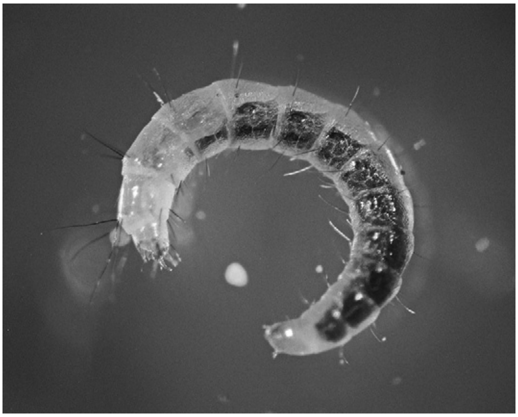

**Fig. 2.** Third instar larva of *C felis.*

direct sunlight in their microhabitat, actively moving deep into carpet fibers or under organic debris (grass, branches, leaves, or soil).[2] Flea larvae undergo two molts, usually over 5 to 11 days, before developing into the pupal stage.[7,8]

Flea larvae are extremely susceptible to heat and desiccation.[8,9] Moisture in the larval environment is essential for development, with relative humidity lower than 50% causing desiccation, and larvae that are maintained in soil with low moisture levels fail to develop.[8] Because larvae are susceptible to heat and desiccation, development outdoors probably occurs only where the ground is shaded and moist. The flea-infested host also needs to spend a significant amount of time in these areas, so that adult flea feces will be deposited into the larval environment.

The mature third instar larva produces a 0.5-cm–long, whitish, loosely spun silklike cocoon in which it undergoes pupation. The cocoon is sticky and becomes coated with debris from the environment. Cocoons are found in soil, in carpets, under furniture, and on animal bedding. At 27°C (80.6°F) and 80% relative humidity, fleas begin to emerge approximately 5 days after pupation, and they reach peak emergence in 8 to 9 days.[10,11] Once the pupa has fully developed, the pre-emerged adult flea within the cocoon can be stimulated to emerge from the cocoon by physical pressure, carbon dioxide, and heat.[12] If the pre-emerged adult does not receive an emergence stimulus, it may remain quiescent in the cocoon for several weeks or months until a suitable host arrives.[12]

The entire life cycle of *C felis* can be completed in 12 to 14 days, or it can be prolonged up to 174 days, depending on temperature and humidity within the microenvironment.[12] However, under most household conditions, nearly all cat fleas will complete their life cycle within 3 to 8 weeks.

The adult *C felis* depends primarily on visual cues to locate hosts.[13] Factors such as flea age, $CO_2$, and temperature modify their responsiveness.[13] It has been determined that *C felis* adults are most sensitive to green light with wavelengths between 510 and 550 nm.[13,14] *Ctenocephalides felis* adults that have emerged in dark areas, such as under porches, in crawl spaces, or under beds or sofas, will orient and move toward a light source. They then jump when the light source is suddenly and temporarily interrupted (host-shadow).

If the newly emerged *C felis* adults do not immediately acquire a host, they can survive several days before requiring a blood meal. As with immature life stages, survival of adult fleas is highly dependent on temperature and humidity. In moisture-saturated air, 62% of adult *C felis* survived for 62 days, whereas only 5% survived for 12 days when maintained at 22.5°C and 60% RH (relative humidity).[10,15] It is unlikely that adult or immature fleas in the premises can survive during winter in northern temperate regions. It has been shown that no life cycle stage (egg, larva, pupa, or adult) can survive for 10 days at 3°C (37.4°F) or 5 days at 1°C (33.8°F).[10]

Numerous warm blooded animals play host to *C felis*. In North America, various nondomesticated hosts that harbor cat fleas have been reported, including coyotes, red and gray fox, bobcats, skunks, several rodent species, raccoons, opossums, Florida panthers, poultry, calves, and ferrets.[1,2] With such a large number of alternative hosts, several of which often live in close proximity to humans and their pets, it is likely that flea-infested wild animals or feral dogs and cats are serving as continual sources of reinfestation. Newly emerged fleas, in carpets or outdoors, often bite humans before colonizing their preferred host. Because *C felis* is not highly cold-tolerant, it has been postulated that it is surviving in cold climates in the urban environment, as adults on untreated dogs and cats or on small wild mammals, such as opossums and raccoons.[1,2] Because these animals pass through yards in the spring, or establish nesting sites in crawl spaces or attics, eggs drop off and develop into adults. Cat fleas may also survive the winter, as pre-emerged adults in microenvironments that are protected from the cold.[1,2]

Once on a host, *C felis* initiates feeding within seconds to minutes.[16] In one study, approximately 25% of fleas were blood-fed within 5 minutes, and in another, the volume of blood consumed by fleas was quantifiable within 5 minutes.[17,18] Mating occurs on the host after feeding and can occur within 8 to 24 hours.[16] Female cat fleas begin egg production within 24 to 36 hours of their first blood meal.[19] They lay eggs within the pelage of the host, but because the eggs are not sticky, they drop out of the hair into the surrounding premises. *Ctenocephalides felis* is a highly fecund organism, with the female reaching peak egg production at 40 to 50 eggs per day and producing approximately 1300 eggs during the first 50 days on a host. C*tenocephalides felis* can continue to produce eggs at a gradually declining rate for more than 100 days.[19] To produce such a large quantity of eggs, female cat fleas consume an average of 13.6 μL of blood per day, which is equivalent to 15.15 times their body weight.[16] While feeding, female cat fleas excrete large quantities of incompletely digested blood, which dries within minutes into reddish-black fecal pellets or tubular coils that are often called "flea dirt" or "frass." Flea feces can often be found matted into the pelage.

Actively feeding and reproducing *C felis* adults are fairly permanent ectoparasites. 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.[19] When fleas that have been on a host for several days are removed, they die within 1 to 4 days.[15] Although cat fleas rarely leave their host voluntarily, the host's grooming activity plays a significant role in their survival and longevity on that host. When cats are allowed to groom freely, they will ingest or groom off a substantial number of fleas in a few days.[10,20] When cat fleas were allowed to feed for only 12 hours and then removed from their host, 5% were still alive at 14 days.[15] This is of particular importance, because one study showed that when cats were housed adjacent to each other but physically separated, 3% to 8% of the fleas moved from one cat to another. However, when cats were housed in the same cage, 2% to 15% of the fleas transferred. Therefore, it is possible for a few adult fleas to transfer from one host to another.[21] However, it is far more likely that most flea infestations originate from previously unfed fleas emerging from environments that have supported development of immature life stages.

## TICK OVERVIEW

There are two primary tick families, Argasidae (soft ticks) and Ixodidae (hard ticks). In North America, the ticks of most importance to dogs, cats, and their owners are the Ixodidae or hard ticks. Hard ticks are characterized by a hardened dorsal shield (scutum) and a head (capitulum) that extend in front of the body. Many species also have eye spots on the scutum and posterior indentations called festoons that can be used to aid in identification. Additionally, the Ixodidae commonly found on dogs and cats in North America are all three-host ticks, feeding once on a different host after molting in each motile stage (larva, nymph, and adult).[22,23]

Most ticks in motile life stages that infest dogs and cats use an ambush technique called questing, although *Ixodes spp* may use ambush and hunter tactics.[23] Ticks do not jump onto hosts or drop out of trees. Ticks that use the ambush strategy climb onto weeds, grasses, bushes, or other leafy vegetation, extend their forelegs that contain a sensory apparatus called the Haller organ, and wait for passing hosts to brush against the vegetation. When the host brushes against the plant, the tick immediately releases the vegetation and crawls onto the host.

Mating by ticks in the genera *Amblyomma, Dermacentor,* and *Rhipicephalus* occurs on the host after feeding. Certain species of *Ixodes* often mate off the host before feeding, but may mate while on the host.[24] During the first 24 to 36 hours following attachment to the host, little or no ingestion of blood takes place.[25] During this period, ticks use their chelicerae to cut the epidermis and insert their hypostome, which contains backward directed spines. Following insertion of the hypostome, many ticks reinforce their attachment by secreting a cementlike substance from their salivary glands.[23,26] Once the feeding site is established, the tick begins the second slow feeding phase, which lasts for several days. The slow feeding phase is followed by a rapid feeding phase. During the rapid feeding phase, which occurs 12 to 36 hours before detachment, the mated female tick may increase dramatically in size, often reaching 100 times her unfed body weight.[25,26]

## TICKS SPECIES INFESTING DOGS AND CATS

The tick species that most commonly infest dogs and cats in North America are *Amblyomma americanum* (Lone Star tick), *Amblyomma maculatum* (Gulf Coast tick), *Dermacentor occidentalis* (Pacific Coast tick), *Dermacentor variabilis* (American dog tick), *Dermacentor andersoni* (Rocky Mountain wood tick) *Ixodes pacificus* (western black-legged tick), *Ixodes scapularis* (black-legged tick), *Otobius megnini* (spinose ear tick) and *Rhipicephalus sanguineus* (brown dog tick).[22,23]

### Amblyomma *spp*

*Amblyomma americanum* (Lone Star tick) is named for the characteristic and easily recognizable single white spot that occurs on the dorsal shield of the female (**Fig. 3**). The males are also ornate but have several white to yellow lines on the edge of their scutum instead of the single white spot (see **Fig. 3**). *Amblyomma americanum* have long palpi, a long hypostome, eye spots, and festoons.

The range of *A americanum* seems to be increasing across the southern plains and Midwestern and eastern states. It was once considered to occur primarily in the south, with southern New Jersey being its northernmost range; its geographic range has since expanded.[27] Focal populations now occur in many northern states, including Connecticut, Maine, Massachusetts, Michigan, New Jersey, and New York.[27,28] The range of distribution extends south into Florida, west to Texas, and north through eastern Oklahoma and Kansas to Michigan.[27]

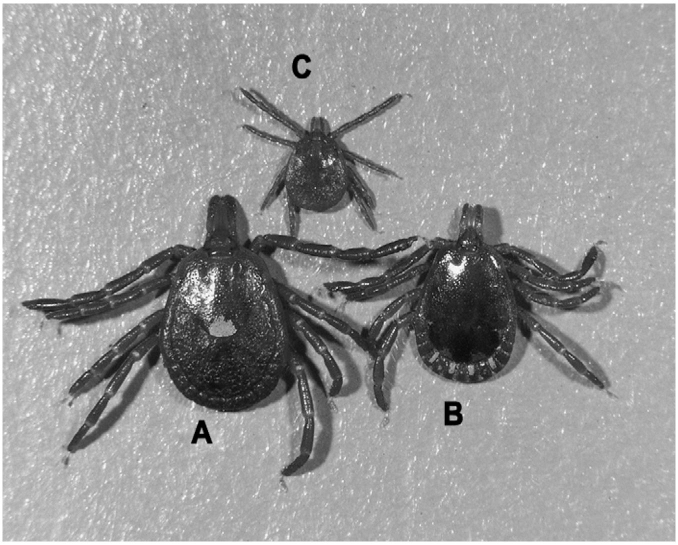


**Fig. 3.** Female (A), male (B), and nymph (C) of *A americanum* ("Lone Star tick").

Several factors have contributed to the increased range of *A americanum*, including increased habitat and wide host range that includes deer, small mammals, birds, and humans.[27,29] This tick occurs most commonly in woodland habitats with dense underbrush. Substantial reforestation over the last century, in urban and rural habitats, has provided increased areas of habitat for white-tailed deer and for survival and expansion of *A americanum*.[27,29] The white-tailed deer is considered a preferred host for *A americanum*, and all life stages will feed on white-tailed deer.[27,29]

It is well recognized that before and in the early-to-middle part of the nineteenth century, white-tailed deer were numerous and widespread throughout North America. Throughout the nineteenth century, unregulated hunting, loss of natural predators, and extensive loss of habitat decimated deer populations.[27,29] By the beginning of the twentieth century, only an estimated 300,000 to 500,000 deer remained in North America.[31] During the early and middle part of the twentieth century, restrictions were placed on deer hunting, numerous states began restocking efforts, and combined with an increase in natural habitat, there was a marked resurgence in deer populations to an estimated 18 million by 1992.[29] As deer expanded their range and increased their numbers, there was a corresponding increase in the tick species that are closely associated with deer.

White-tailed deer populations are so important to the long-term survival of *A americanum* that exclusion of deer has a profound effect on its populations. In one study, exclusion of deer from a 71-ha forest over a 4-year period resulted in reductions of 88%, 53%, and 51% of the larvae, nymphs, and adults, respectively, as compared with control plots.[30]

Another excellent host for larvae and nymphs that uses similar habitats is the wild turkey.[27,31] Areas with a deciduous forest canopy and high populations of white-tailed deer and wild turkey can have remarkably large populations of *A americanum.* Many other animals can be parasitized by this aggressive tick. Immature stages can be found on various ground-dwelling birds and numerous mammals such as red fox, rabbits, squirrels, raccoons, dogs, cats, coyotes, deer, and humans.[22,27] Adult

*A americanum* also feeds on various hosts, including cats, cattle, coyotes, deer, dogs, horses, sheep, raccoons, and humans.[22,27]

As *A americanum* populations expand into new areas, seasonality of ticks found on dogs and cats can change. Nymphs are found from March to September, larvae are frequently encountered in the late summer into the fall, and adults are often encountered from late February to early June.[27,31] Because all life stages can parasitize dogs and cats, *A americanum* could be encountered on pets, 8 to 9 months out of the year. Once hosts are acquired, larvae and nymphs engorge over a period of 3 to 9 days, and adults typically engorge within 9 days, but may take up to 2 weeks to do so.[27,31] As with most ticks, peak seasonal activity can vary widely by geographic region.

Similar to other ixodid ticks, unfed adults may survive for prolonged periods (>400 days) if hosts are not available. In temperate climates, the life cycle often takes 2 years to complete, whereas in warmer coastal climates, it can be completed within 1 year.[32]

*A americanum* is considered a major vector of animal and human pathogens, including *Ehrlichia chaffeensis* (causing human monocytic ehrlichiosis) and *Ehrlichia ewingii*.[27] The Lone Star tick can also transmit *Borrelia lonestari*.[33] It has also been implicated in the transmission of *Francisella tularensis* (causing tularemia).[34] The Lone Star tick has also recently been demonstrated to be a competent vector of *Cytauxzoon felis*, the highly pathogenic and usually fatal protozoan parasite of cats.[35]

Another *Amblyomma* species that parasitizes dogs is the Gulf Coast tick, *A maculatum* (**Fig. 4**). *Amblyomma maculatum* is a three-host tick with larvae and nymphs feeding on small rodents and ground dwelling birds, such as quail, meadow larks, and cattle egrets. Adults primarily parasitize the ears of large mammals, such as cattle, but they will also feed on horses, pig, goats, dogs, bear, birds, bobcats, coyotes, rabbits, raccoons, deer, and humans.[36] Once considered to be restricted within a 100-mile strip along the Gulf and Atlantic Coasts, *A maculatum* is now recognized to extend further inland, particularly in the Central United States, with expansion into Oklahoma and eastern Kansas.[37–39] *A maculatum* transmits *Hepatozoon americanum*, the etiologic agent of American canine hepatozoonosis. The transmission of this disease is unique, in that dogs must ingest the tick to become infected.[40] *Amblyomma maculatum* also has been documented to cause tick paralysis.[22]

**Fig. 4.** Adult female *A maculatum* ("Gulf Coast tick").

### Dermacentor *spp*

*Dermacentor variabilis* is an ornate Ixodidae. The scutum, which covers the entire dorsal surface of the male and the anterior one-third of the unengorged female, is covered with white markings. It also has festoons on the posterior abdomen, eye spots, and short palpi (**Fig. 5**).

*Dermacentor* sp ticks are one of the most widespread and common ticks, infesting dogs and cats in North America. *Dermacentor variabilis* (American dog tick) occurs in the eastern United States from Florida to southern New England and from the Atlantic Coast to the eastern sections of the Plains States.[41] Populations also occur along the Pacific Coast. This tick commonly occurs in grassy meadows, young forests, and along roadways and trails.[41]

The seasonal tick activity of *D variabilis* is similar across its wide geographic range, but variations in peak activity do occur. In the northern areas of the United States and Canada, adults are active from April to August, with a single period of peak activity in May to June.[41] In Kentucky, adults became active in early-to-mid–April followed by two periods of peak activity, one from mid-to-late–May and another in July.[42]

Larvae of *D variabilis* feed on small rodents, such as voles and mice. In the southern United States, larvae, hatching from eggs that are laid during the early summer, can undergo two distinct periods of host seeking. Some larvae may seek hosts in late summer, but others will enter diapause in the fall. These larvae will not seek hosts until early February and will continue this activity for 2 to 3 months.[41] Once attached, larvae can take from 3 to 12 days to engorge, averaging 4 days typically.[41]

Questing activity of nymphs quickly follows larval activity during the spring and early summer, as soil temperatures warm.[41] Common hosts for nymphs include cats, dogs, opossums, rabbits, raccoons, and other medium-to-small sized mammals. Similar to larvae, nymphs feed for only a few days and require from 3 to 11 days to engorge.[41]

Adults may seek hosts that same summer after molting but often overwinter and begin questing the following spring.[41] Common hosts for adult *D variabilis* include cats, dogs, cattle, horses, and other large mammals, including humans. Similar to males in the genera *Amblyomma* and *Rhipicephalus*, males in the genus *Dermacentor* feed sparingly and do not engorge. Female *D variabilis* are typical of many ixodid ticks,

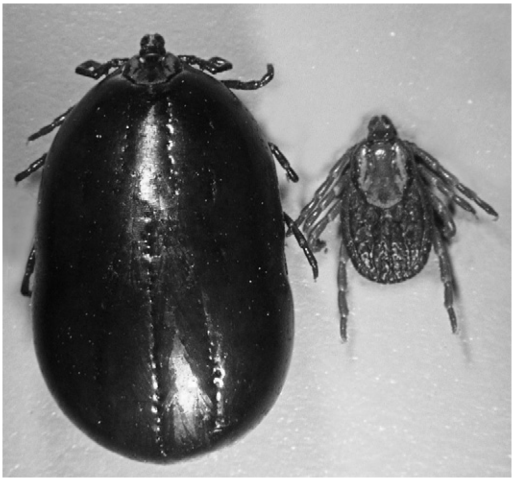

**Fig. 5.** Engorged (*left*) and nonengorged females of *D variabilis* ("American dog tick").

in that they engorge markedly on blood and often increase more than 100 times in size. Fully engorged *D variabilis* females drop from their hosts within 4 to 10 days and deposit between 4000 to 6500 eggs.[42] The life cycle can be completed in 3 months in the southern United States, but it may take up to 2 years in more northern climates. Similar to other ixodid ticks, unfed adults can survive for protracted periods without feeding. Adult *D variabilis* can live more than 2 years without feeding if hosts are not available.[41] An adult tick found on a dog may have originated from eggs laid 2 to 4 years previously, because it can survive the various stages for prolonged periods, awaiting appropriate hosts on which to feed, and because it often takes 2 years to complete development from egg to adult.

*Dermacentor andersoni* is found in at least 14 western US states and in southwestern Canada.[43,44] In the United States, populations extend from western Nebraska and the Dakotas to Washington and Oregon, south through the eastern counties of California, then east through northern Arizona and New Mexico.[43] The life cycle of this three-host tick often takes 2 to 3 years. Similar to *D variabilis,* the larvae and nymphs of *D andersoni* feed on small mammals for 3 to 5 days. Adult *D andersoni* parasitize large mammals including horses, cattle, dogs, sheep, deer, bears, coyotes, and humans.[43] Adults usually occur from March to June, but are most numerous in April.[43,44] This tick can also survive for prolonged periods without feeding, with larvae and nymphs surviving for more than a year without a host, and adults, for more than 2 years.[43] It is similar in appearance to *D variabilis*, but adults of *D andersoni* have larger goblets on the spiracular plates than *D variabilis*.

Another *Dermacentor* species that is also regionally important is *D occidentalis* (Pacific Coast tick). It is widely distributed in the state of California, except for the very dry regions of the central valley and the southeast. The only other areas from which it has been collected are southwest Oregon and Baja, Mexico.[45,46] It is a three-host tick, commonly feeding on rodents, rabbits, and squirrels in the immature stages, and on cattle, dogs, horses, deer, and humans as adults.[46]

*Dermacentor* sp ticks are important vectors of disease. *Dermacentor variabilis* has been implicated in the transmission of cytauxzoonosis (*Cytauxzoon felis*).[47] *Dermacentor variabilis* and *D andersoni* are the primary vectors of Rocky Mountain spotted fever (etiologic agent, *Rickettsia rickettsii*) to dogs and humans.[23] In North America, both species are most commonly associated with tick paralysis. They can also transmit *Francisella tularensis*.[35]

### Ixodes *sp*

*Ixodes scapularis,* the black-legged tick, (deer tick or Lyme disease tick) is an inornate tick without eyes or festoons. Larvae are small and often difficult to see. They are about 0.5 mm long, flat, six-legged, and nearly translucent.[48] Nymphs are approximately 1 mm long and darker. Unfed males are approximately 2 mm long and unfed females, about 2.5 mm.[48] There are considerable morphologic differences between male and female *Ixodes* (**Fig. 6**). Males are dark brown, almost black, with shorter palps than females. Females have longer mouthparts and appear two-toned. In the unengorged female, the inornate dorsal shield covers the anterior one-third of the body, leaving the orange-brown posterior portion of the body exposed.

*Ixodes scapularis* is widely distributed in the eastern and central United States in at least 35 states.[48,49] Its distribution is from Florida to Maine, west into far eastern South Dakota, and south through eastern Kansas into central Texas.[48,49] *Ixodes scapularis i*s also located in central and eastern Canada.[50]

Similar to *A americanum,* the distribution of *I scapularis* correlates to the distribution and abundance of white-tailed deer.[48,51] Exclusion of deer dramatically decreases

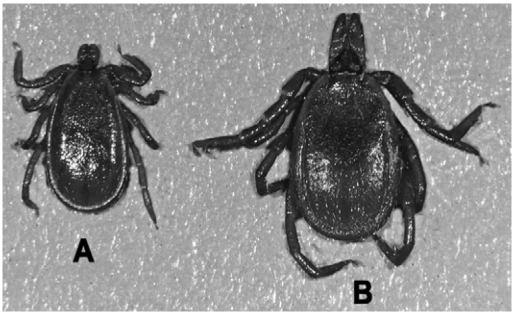


**Fig. 6.** Male (A) and female (B) of *I scapularis* ("eastern black-legged tick"; "deer tick").

*I scapularis* populations.[52] On Mohegan island, off the coast of Maine, annual fall flagging for ticks produced an average of 6 to 17 adult *I scapularis* per hectare, and up to 18 larvae per rat.[52] During an approximate 2.5-year period, all the deer were removed from the island. Within 4 years of deer removal, no immature ticks were found on rats and only 0.67 adult ticks per hectare were found during flagging of vegetation.[52]

Although white-tailed deer are widely distributed across the central and eastern United States, the abundance of *I scapularis* is not always directly related to the abundance of deer populations. Tick populations can vary markedly across a region due to soil type, moisture, and forest cover.[53,54] In the north central United States, *I scapularis* was found to be more numerous in areas with a deciduous forest canopy and where soil textures were classified as sandy or loam-sand.[53]

Seasonal activity varies by geographic region, but larval activity is generally highest in August and September. Larvae attach to and feed on various small mammals, including mice, chipmunks, and shrews. Larvae also feed on birds and lizards.[50] The white-footed mouse (*Peromyscus leucopus*) is of particular importance in tick life cycle and disease transmission, because it serves as a good host for larval *I scapularis* and it is a major reservoir of *Borrelia burgdorferi*.[50,55]

Immature ticks engorge typically for 2 to 4 days before dropping off to molt in moist protected areas, such as under leaf litter in forested habitats.[56] Larvae overwinter and then molt to nymphs in the spring. Nymphs will feed for 3 to 4 days on various hosts, including mice, squirrels, chipmunks, raccoons, opossums, skunks, shrews, cats, birds, and humans.[48,49,51] Nymphs occur primarily from May through July in the north and January through September in the south.[48,56] Adults occur most commonly from October to December. Adults that do not find a host will quest again, typically from March to May.[51] Adults feed for 5 to 7 days, primarily on white-tailed deer, but also on bobcats, cattle, coyotes, dogs, foxes, horses, humans, opossums, raccoons, and other mammals.[48,55]

*Ixodes scapularis* is the vector of *B burgdorferi* (causing Lyme disease) in the central, upper Midwestern, and northeastern United States; it is also the vector of *Anaplasma phagocytophilum* (causing human granulocytic ehrlichiosis), and *Babesia microti* (causing human babesiosis).[23] *Ixodes scapularis* may also cause tick paralysis.

The western black-legged tick, *I pacificus,* is morphologically similar to *I scapularis.* It is the vector for *B burgdorferi* and *A phagocytophilum* in the western United States.[55] Populations of *I pacificus* are distributed from Mexico to British Columbia, with localized populations in Utah and Arizona.[46,49,57,58] It is found primarily in leaf litter, under deciduous trees, and it favors cooler, moister coastal climatic conditions. Larvae and nymphs feed on various animals, including lizards, small rodents, squirrels, rabbits, cougars, black-tailed deer, ground nesting birds, and humans.[59,60] The primary hosts for larvae and nymphs are the western fence lizard *(Sceloporus occidentalis*) and the southern alligator lizard *(Elgaria multicarinata).* Adults are also found on a various hosts, including deer, elk, black bear, bobcats, dogs, cats, coyotes, cougars, horses, cattle, and humans.[60]

Nymphs, typically, are present and active by mid-March, peak by early May, and are absent by late July to mid-August.[59] Adult ticks are found most often, from October to June (winter/spring), during the period of the year when humidity is usually high.

### Rhipicephalus *sp*

*Rhipicephalus sanguineus* (brown dog tick) is reddish brown and inornate (**Fig. 7**). The basis capitulum is hexagonal and eyes and festoons are present. Tick species are often restricted in their distribution because of evolutionary adaptation to specific hosts and ecological factors. However, because dogs are the primary host for *R sanguineus,* they are widely distributed in tropical and temperate regions, wherever dogs are found. *Rhipicephalus sanguineus* seems to be well adapted to dogs as their natural host. Consequently, dogs do not develop resistance to *R sanguineus* infestations.[61] Although dogs are the primary host, immature life stages can be found on rodents and other small mammals. Rarely, adults can be found on other mammals, such as cats and humans.[61]

Most ixodid ticks develop outdoors. *Rhipicephalus sanguineus*, an exception, is commonly found in indoor environments. It is the only tick that infests human dwellings and kennels in North America. Although it seems to be cold-intolerant, *R sanguineus* can withstand areas of low humidity, and it persists in temperate regions by inhabiting kennels and homes.[61] These ticks often crawl up walls and can be found above artificial ceilings.[1,60]

Adult ticks can be found throughout the hair coat, but they are most commonly located in the ears or between the toes of dogs. Adults ticks feed for 5 to 21 days.[61] After engorgement, adult females drop off and deposit up to 4000 eggs. The eggs are often deposited in cracks and crevices along floors, behind dog cages, or even in ceilings.[61] Eggs can hatch within 20 to 30 days. Although preferring dogs, immature ticks will also feed on rodents and rabbits.[23] Larvae and nymphs feed over a period of 3 to 11 days, and they are commonly distributed along the back and neck of dogs.[61] As with many hard ticks, ticks in unfed stages can survive for prolonged

**Fig. 7.** Male *R sanguineus* ("brown dog tick").

periods in the environment. Unfed larvae, nymphs, and adults can survive for up to 8, 6 and 19 months, respectively.[61] The life cycle may be completed in as little as 63 to 91 days. This results in a rapid increase in tick populations, and it can make infestations of homes or kennels extremely difficult to eradicate.[61]

Previously attached *R sanguineus* has been shown to transfer from one dog to another.[62] In cohoused dogs, ticks, previously attached to one dog, emigrated to other dogs. This was particularly evident in males, when female ticks were no longer present.[62] This movement of ticks between hosts has major potential implications for intrastadial (within life cycle stage) disease transmission. *Rhipicephalus sanguineus* is the vector of numerous important pathogens, including *Ehrlichia canis* (causing canine monocytic ehrlichiosis) and *Babesia canis* (causing canine babesiosis).[23] It may also transmit *Anaplasma* (formerly *Ehrlichia*) *platys* and *Babesia gibsoni*.[63,64] Recently, in the southwestern United States, *R sanguineus* was identified as a vector for *R rickettsii*, the etiologic agent of Rocky Mountain spotted fever.[65]

## Otobius *sp*

*Otobius megnini* (spinose ear tick) is the only soft tick (Argasidae) that is an important ectoparasite of dogs and cats in North America. It has no dorsal shield and the capitulum is positioned under the body (**Fig. 8**). *O megnini* is unusual, with only the larvae and nymphs being parasites. Larvae, which resemble small shriveled grapes, infest the ears of livestock and occasionally, dogs and cats.[66,67] Larvae feed for 6 to 9 days before molting to the first stage nymph on the host.[66,67] First stage nymphs stay in the ear and feed for 8 to 9 days. They molt to second stage nymphs and feed for an additional 10 to 12 days.[67] Both nymphal stages have a spiny cuticle from which the tick derives its name. Engorged nymphs drop from the host and crawl into cracks and crevices, under stones, or under tree bark, where they develop to adults. Development from larva to adult requires 62 to 107 days.[67] Adults do not feed, and mating occurs in the environment. Several hundred to more than 1000

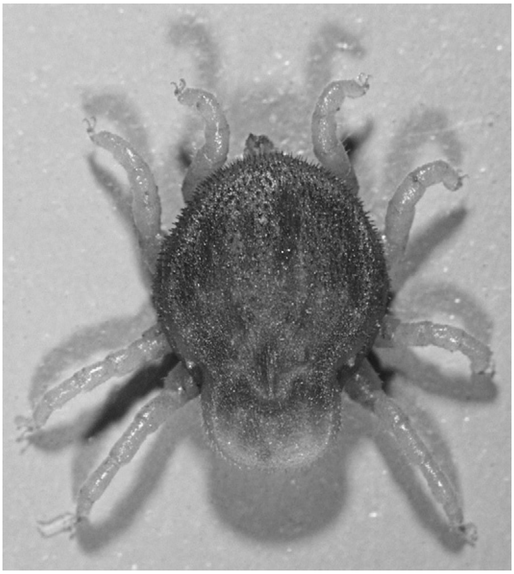

**Fig. 8.** Nymph of *O megnini* ("spinose ear tick").

eggs are deposited into the environment over a few weeks.[67] Larvae and nymphs feed on numerous mammals, including cats, cattle, coyotes, deer, dogs, goats, horses, humans, mules, rabbits, and sheep (including bighorn sheep).[67] In North America, the spinose ear tick is generally found in drier areas of the western and southwestern United States, but it also occurs in Hawaii and British Columbia.[67,68] It can easily be transported to other areas, while in the ear canals of dogs, cats, and livestock. *O megnini* has been implicated in the transmission of *Coxiella burnetii* (causing Q fever).[69]

## CONTROL OF FLEAS AND TICKS

Control of fleas and ticks on companion animals and in the environment can be challenging.[1,2,70–72] Strategies for successful elimination of fleas from pets and their environments will differ in some respects from measures used for successful tick control. Each will be addressed separately and will be followed by a discussion of the available agents commonly used for flea or tick control. These agents are summarized in **Table 1**.

### *Flea Control*

Successful control of pet flea infestations usually involves a combination of strategies.[70,73,74] These include host-targeted and environmental insecticides and mechanical means of reducing or eliminating environmental flea stages. Mechanical means of environmental control include washing of pet bedding or bed cloths frequented by pets. Vacuuming of carpets, furniture cushions, rugs, or other substrata, with a vacuum machine containing a "beater bar," will remove many of the flea eggs and larvae. In addition, cocooned pupae at the upper levels of the carpet can also be affected. The vibration also stimulates adult fleas to emerge from their cocoons so that they can be collected in the vacuum machine. Therefore frequent vacuuming, during a flea infestation, can reduce the overall flea burden in the home. It should be ensured that vacuum bags are disposed of properly, to prevent recolonization of the home with flea stages previously removed by vacuuming. Because outdoor development of immature flea life stages is limited to shaded areas, altering outdoor environments to eliminate such habitats can effectively reduce flea populations. Because urban wildlife, such as opossums, raccoons, and foxes, are good hosts for cat fleas, pet owners should avoid encouraging visitations by wildlife, which will affect flea and tick control (see later discussion). Treatment of indoor and outdoor environments with insecticides requires knowledge of what to use and where to use it. For this reason, it is suggested that pet owners consult with a licensed pest control specialist for such applications.

Numerous safe and effective host-targeted flea-control agents are available. Available agents include topical (imidacloprid, dinotefuran, fipronil, metaflumizone, selamectin) and oral (spinosad, nitenpyram) adulticides (see **Table 1**). Some single entity or combination flea products are also effective against ticks. Because topical products reside in the superficial layers of the skin, their residual efficacy can be affected by excessive water immersion and shampooing.[74] However, available research suggests that topical products have substantial residual activity, if wetting or bathing is not practiced in excess. Certain descaling and follicle-flushing shampoos are more likely to affect residual flea control than are simple detergent (grooming) shampoos. Orally administered flea-control products remain unaffected by wetting and bathing; however, these products have activity against fleas only (see **Table 1**). Some flea-control formulations also combine adulticides with insect growth regulators

**Table 1**
**Summary of selected flea and tick control products**

| Active Ingredients (Product Name) | Target Animal (Minimum Age) | Formulations[a] | Parasite Claims: *C Felis* Adult | *C Felis* Eggs | Ticks Unspecified | *A Americanum* | *A Maculatum* | *D Variabilis* | *I Scapularis* | *R Sanguineus* | *Cheyletiella Yasguri* | *Otodectes Cynotis* | *Sarcoptes Scabiei* | Chewing Lice | Biting Flies | Mosqui-toes | Gnats |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amitraz (Preventic Tick Collar) | Dog (12 Wk) | 9% amitraz collar | | | ■ | | | | | | | | | | | | |
| Dinotefuran, pyriproxyfen, permethrin (Vectra 3D) | Dog (7 Wk) | 4.95% Dinotefuran, 36.8% permethrin, 0.44% pyriproxyfen topical spot-on | ■ | ■[b] | | | ■ | ■ | ■ | ■ | | | | ■[b] | ■[b] | ■ | |
| Dinotefuran, pyriproxyfen (Vectra for Cats) | Cat (8 Wk) | 22% dinotefuran, 0.44% pyriproxyfen topical spot-on | ■ | ■[b] | | | | | | | | | | | | | |
| Fipronil, (S)-methoprene (Frontline Plus) | Dog, cat (8 Wk) | 9.8% fipronil, 11.8% (C) or 8.8% (D) (S)-methoprene topical spot-on | ■ | ■ | | ■ | | ■ | ■ | ■ | | | ■D | ■ | | | |
| Fipronil (Frontline Top Spot, Frontline Spray) | Dog, cat (8 Wk) | 9.7% fipronil topical spot-on; 0.29% fipronil spray | ■ | | | ■ | | ■ | ■ | ■ | | | ■D | ■ | | | |
| Imidacloprid (Advantage) | Dog, cat (7 Wk [D]; 8 Wk [C]) | 9.1% imidacloprid topical spot-on | ■ | | | | | | | | | | | ■D | | | |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Imidacloprid, permethrin | Dog (7 Wk) | 8.8% imidacloprid, 44.0% permethrin topical spot-on | ■ | | | ■ | | ■ | ■ | ■ | | | | ■ | ■ | ■ | |
| Imidacloprid, moxidectin (Advantage Multi) | Dog, cat (7 Wk, 3 lbs [D]; 9 Wk, 2 lbs [C]) | 10% Imidacloprid, 2.5% moxidectin [dog], 1% moxidectin [cat] topical spot-on (w/v) | ■ | | | | | | | | | ■C | | | | | |
| Lufenuron (Program, Sentinel) | Dog, cat (4 Wk, 6 Wk [injectable]) | 46, 115, 230, or 460 mg per tablet (dog), 90, 204 mg per tablet (cat), 135, 270 mg suspension (cat), 0.4 mL, 0.8 mL injectable syringes (cat) | | ■ | | | | | | | | | | | | | |
| Metaflumizone, amitraz (Promeris for dogs)[c] | Dog (8 Wk) | 14.34% metaflumi-zone, 14.34% amitraz topical spot-on | ■ | | | ■ | | ■ | ■ | ■ | | | | ■ | | | |
| Metaflumi-zone (Promeris for cats) | Cat (8 Wk) | 18.53% metaflumi-zone topical spot-on | ■ | | | | | | | | | | | | | | |

(*continued on next page*)

**Table 1**
**(*continued*)**

| Active Ingredients (Product Name) | Target Animal (Minimum Age) | Formulations[a] | Parasite Claims: *C Felis* Adult | *C Felis* Eggs | Ticks Unspecified | *A Americanum* | *A Maculatum* | *D Variabilis* | *I Scapularis* | *R Sanguineus* | *Cheyletiella Yasguri* | *Otodectes Cynotis* | *Sarcoptes Scabiei* | Chewing Lice | Biting Flies | Mosquitoes | Gnats |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitenpyram (Capstar) | Dog, cat (4 Wk, 2 lbs) | 11.4 and 57 mg tablets | ■ | | | | | | | | | | | | | | |
| Permethrin (Proticall) | Dog (4 Wk) | 65% permethrin topical spot-on | ■ | | | ■ | | ■ | ■ | ■ | ■ | | | ■ | | ■ | |
| Permethrin, pyriproxyfen (Virbac Long Acting Knockout Spray) | Dog (6 months) | 2% permethrin, 0.05% pyriproxyfen spray | ■ | ■ | ■ | | | | | | | | | | | | |
| Pyrethrins (Virbac Pyrethrin Dip) | Dog, cat (12 Wk) | 1% pyrethrin dip | ■ | | ■ | | | | | | | | | ■ | ■ | ■ | ■ |
| Selamectin (Revolution) | Dog, cat (6 Wk [D], 8 Wk [C]) | 6% (C) or 12% (D) spot-on; tubes contain 15, 30, 45, 60, 12 or 240 mg of selamectin (w/v) | ■ | ■ | | | | ■D | | | | ■ | ■D | | | | |
| Spinosad (Comfortis) | Dog (14 Wk) | 140, 270, 560, 810, 1620 mg per tablet | ■ | | | | | | | | | | | | | | |

See specific product inserts for dosage regimens and other details of product use. Certain products also prevent heartworm infection and treat or control certain gastrointestinal parasites in dogs or cats.

*Abbreviations:* C, cat; D, dog; w/v, weight/volume; w/w, weight/weight.

[a] All percentage concentrations are w/w unless specified as w/v.

[b] Also labeled for control of flea larvae and pupae and sand flies, sucking lice, and mites that cause dandruff and scale.

[c] Also labeled for control of *Demodex* spp.

(IGRs) (eg, methoprene, pyriproxyfen) or insect development inhibitors (IDIs) (eg, lufenuron).

Several product properties should be considered when designing a flea-control program and selecting flea-control agents. Among them are speed of action, duration and spectrum of activity, route of administration, and systemic versus topical action of the product.[73] These properties may be important if the pet suffers from flea allergy dermatitis (FAD), if owner compliance (including capability to administer the product) is inconsistent, if pet wetting or bathing is excessive, or if treatment or control of other parasites is necessary or desirable. Speed of action can be important if limited flea feeding is desirable, as in severely flea-allergic pets, or if fleas are biting pet owners. Once flea control is initiated, even if aggressive environmental flea control is a component, immature flea life stages will continue to develop, and fleas are still likely to emerge at some level. Therefore, a continuing flea problem should be expected for several weeks after treatment has begun. This necessitates an understanding of the cause of the problem and the persistence to see it through.

As mentioned previously, FAD is probably the most common allergic canine skin disease in certain regions of the United States.[75] It is caused by an atypical and exaggerated immune response to antigens present in flea saliva. At present, at least 15 potentially immunogenic (allergenic) components have been described. These are complete antigens and not haptens. Dogs with FAD can present with several types of hypersensitivity: Type I (immediate) hypersensitivity; Type IV delayed hypersensitivity; and cutaneous basophil hypersensitivity (CBH). Type I hypersensitivity is a humoral response that occurs in a few minutes. It is triggered by immunoglobulin E (reaginic antibody) binding to mast cells, resulting in the release of inflammatory mediators, such as histamine, serotonin, and leukotrienes. Type IV reactions are cell-mediated and involve interactions of T lymphocytes. Release of numerous lymphokines results in the release of pruritogenic inflammatory mediators. CBH is a transient delayed-type reaction in which basophils comprise the principal cell population. Type I and Type IV reactions (particularly Type I) are the reaction basics sought in intradermal skin tests for flea allergy.

Flea bite dermatitis (FBD), the typical reactions to irritation caused by flea bites, and FAD are two distinctly different conditions. Some think that all cases of FBD involve some degree of allergy. In the experience of the authors, nonallergic dogs usually present with fleas and demonstrate few signs of typical FAD. Normally, they have mild skin irritation, acute moist dermatitis (‘‘hot spots’’), or acral lick granulomas. Often between 3 and 5 years of age, allergic dogs present with crusted papules with erythema and/or alopecia, lichenification, or hyperpigmentation, usually on the dorsal lumbosacral area, caudomedial thighs, or ventral abdomen. In many cases, atopic dogs also suffer concurrently from FAD. In true cases of FAD, the ears, feet, and face are usually devoid of lesions. Dogs with FBD and FAD are frequently infected with *Dipylidium* tapeworms. FAD in dogs must be differentiated from food and atopic allergies; other parasitic dermatoses, such as lice and *Cheyletiella*; dermatophytosis; demodicosis; and superficial pyoderma. Dogs that are intermittently exposed to fleas are more likely to develop FAD than dogs that are chronically exposed to fleas. Consequently, if a dog is treated irregularly or flea control is discontinued until fleas reappear, the intermittent nature of this flea challenge is more likely to result in the development of FAD. The authors have observed this in their colonies of cats that are used as propagation subjects for fleas. The cats are infested weekly with fleas. Because cats tend to remove many fleas from the hair coat during grooming, the authors are, in essence, pulsing them with fleas at weekly intervals. This has lead to the frequent development of FAD in their colonies. When severe FAD exists, persistent or fast-acting host-directed agents, combined with aggressive environmental control measures, are usually necessary to control fleas and maintain pets below their responsive allergic threshold

### *Tick Control*

Control of ticks also involves targeting pet animals and addressing the pet's environment. The former is more difficult for ticks than for fleas, because most ticks of veterinary importance use many hosts other than dogs or cats to complete their life cycle (the exception is *R sanguineus*). Reducing exposure to ticks by being informed about predominant species in the local area and avoiding periods when most ticks are active may also reduce the pet and pet owner's risks of exposure.

Numerous studies support the efficacy of host-targeted tick control products.[76–81] Year-round use of these products is justified because of the various tick species that may infest companion animals, and because ticks are more likely than fleas to be active in colder months or to emerge and quest for hosts during warm-weather breaks. The authors are often asked about proper mechanical methods of removing attached ticks from dogs or cats. Although several tick detachment devices are available, the authors recommend the slow deliberate removal of ticks, with a single slow-motion application of steady pressure, while grasping the ticks as close to the skin at the attachment site as possible.[82] Twisting or crushing the tick should be avoided, because this may result in either failure to remove the intact mouthparts or expulsion of tick gut contents into the host. Leaving mouth parts in the host can result in inflammatory swellings at the site of attachment. Inflammation, due to residual tick mouthparts in the host, is more severe for species that have longer mouthparts, such as *Amblyomma* and *Ixodes.* Expulsion of tick gut contents may further increase the potential for introducing infectious agents. Topical application of fingernail polish, alcohol, petroleum jelly, or any other moiety to attached ticks is ineffective and imprudent. Likewise the use of direct heat (ie, cigarettes or lighters) should be avoided for obvious reasons.

In cases where more aggressive tick control strategies are needed, host-targeted tick control products can be administered in combination, or the frequency of application can be increased. Another option is to move pets to the next product weight range, if the pet's weight is within 10% of the higher weight range. Any or all of these recommendations may be a violation of product label claims.

Environmental control of fleas and ticks usually involves destroying refuge areas of animals that may serve as alternative hosts.[70] It is important to eliminate piles of yard waste such as grass, weeds, and brush, particularly if they are near buildings or kennels that house pets. Although controlled burning of tick habitats, such as grasslands or forest canopies, can provide brief respites from tick infestation, these procedures can be dangerous and unpopular with environmentalists. Brown dog ticks require aggressive kennel- and domicile-control because all stages can use dogs as a suitable hosts. Successful strategies for brown dog tick control include appropriate use of environmental acaricides (ie, synthetic pyrethroids) behind, under, and around cages and in cracks and crevices in floors, walls, and ceiling. Including the ceilings is particularly important because brown dog ticks are inclined to climb upwards in indoor environments. As discussed for fleas earlier, application of environmental tick control products should be performed by professional pest control specialists. It is also prudent to limit access to crawl spaces under homes, decks, and outbuildings, to discourage visits by wildlife. Product properties or issues to be considered when designing regimens for successful tick control include numbers and species of ticks in the pet's environment, expected level of exposure to ticks, prevalence and spectrum of tick-borne diseases, and severity of reactions to tick bites. Several published studies suggest that available tick control products can aid in the prevention of transmission of vector-borne diseases.[83–89]

## FLEA AND TICK CONTROL AGENTS

### *Carbamates, Organophosphates, Organochlorines, Pyrethrins, Pyrethroids, and Others*

These traditional flea and tick control agents have largely given way to newer agents that are discussed in the following sections. Although they remain as active ingredients in some ethical and over-the-counter target animal products and also in many environmental products, they are no longer used for flea and tick control with the frequency that they once were. One exception is permethrin, which remains a component of several newer products. Permethrin will be discussed later with tick control strategies.

### *Imidacloprid*

Imidacloprid is a member of the nitroguanidine subclass of neonicotinoid insecticides[90] (see **Table 1**). These agents were so named because they are related to nicotine in structure and function. Imidacloprid and other neonicotinoids act specifically on insect nicotinic acetylcholine receptors, resulting in rapid inhibition of insect nervous system function.[91] The neonicotinoids can be used safely in dogs and cats because of unique and important structural differences between mammalian and insect acetylcholine receptors. Imidacloprid targets adult fleas, although skin scales, hair, and debris that are shed from treated animals were shown to be larvicidal, when coming into contact with these stages in the pet's environment.[91]

Another strength of imidacloprid is that it can be administered as frequently as once-weekly.[91] This is particularly helpful for animals with severe flea-associated dermatitis.

### *Dinotefuran*

Dinotefuran is a new third generation member of the neonicotinoid class of insecticides. Other members of this class include imidacloprid and nitenpyram. Imidacloprid and nitenpyram bear some resemblance to the nicotine molecule in being chlorinated compounds that share the aromatic pyridine ring of nicotine. Dinotefuran is a nonchlorinated, nonaromatic compound, more similar in structure to acetylcholine than to nicotine.[92] It binds poorly to the insect acetylcholine receptor, suggesting that it possesses a novel site of action. Dinotefuran is available as the single ingredient for adult flea control in cats and is combined with permethrin for adult flea and tick control in dogs. In dog and cat products, dinotefuran is combined with pyriproxyfen to expand its flea activity to include eggs, larvae, and pupae (see **Table 1**).

### *Nitenpyram*

Nitenpyram is a nitroenamine compound. It is chemically similar to imidacloprid, but it differs in formulation, being administered orally rather than topically at a minimum target dose of 1 mg/kg.[91] Nitenpyram is marketed as a rapid flea removal adulticide.[93] Nitenpyram is rapidly eliminated following oral administration. Peak blood levels are achieved in approximately 1 hour. Nitenpyram is eliminated from dogs, mostly by urinary excretion, within 24 hours. Complete elimination requires a bit more time in the cat, with activity for up to 48 hours (see **Table 1**).

## *Fipronil*

Fipronil is a phenylpyrazole insecticide/acaricide currently marketed as a 0.29% alcohol-based spray, and as a 9.7% solution for spot-on administration to dogs and cats. The more popular spot-on product combines fipronil and methoprene (see later discussion) for additional control of flea egg and larvae stages.[94] The mechanism of action of fipronil probably involves fipronil and its principal metabolite, fipronil sulfone.[91] Both molecules act on gamma-aminobutyric acid (GABA)- and glutamate-gated chloride ion channels that are located in the insect nervous system. Glutamate-gated channels have only been observed in invertebrates. Binding of fipronil and fipronil sulfone to GABA receptor sites is much reduced in mammals compared with insects. The target dosage for the fipronil spray formulation is 3 mL/lb (one to two pumps of formulated product per pound). The spot-on is administered at a minimum target dosage of approximately 7.5 mg/kg (see **Table 1**).

## *Selamectin*

Selamectin is a semi-synthetic avermectin compound, derived from doramectin.[95] It is marketed as a isopropanol/dipropylene glycol monomethyl ether-based topical liquid (6% or 12% active) for spot-on application to dogs and cats. Selamectin is the first broad spectrum, single entity endectocide (effective against endo- and ectoparasites) available in a topical formulation for small animals. Selamectin is positioned principally as a topical heartworm preventive and flea-control agent for use in dogs and cats at a minimum target dose of 6 mg/kg.[96] Claims in the dog, in addition to controlling heartworm and fleas (including flea eggs), include controlling *Sarcoptes scabiei*, *Otodectes cynotis*, and *Dermacentor variabilis*. Claims in the cat, again in addition to controlling heartworm and fleas and flea eggs, include controlling *Otodectes cynotis*, intestinal roundworms (*Toxocara cati*) and hookworms (*Ancylostoma tubaeforme*) (see **Table 1**).

## *Spinosad*

The spinosyns are natural products obtained by fermentation from the actinomycete *Saccharopolyspora spinosa*.[97] Several spinosyn products were recovered during the fermentation and purification process. Spinosyns A and D appeared to be the most active and were selected for further development (hence that name spinosad). Spinosad binds to specific sites on insect nicotinic acetylcholine receptors that are different from sites targeted by other nicotinoids and neonicotinoids. Spinosad induces nervous system hyperexcitation in insects, resulting in paralysis. Spinosad also binds secondarily to GABA sites and, as such, may provide additional potentiation of nervous system dysfunction. Spinosad is absorbed quickly after oral administration and is known to exert its effects quickly.[97] Its action remains persistent for approximately 1 month because of extensive plasma protein binding. Spinosad is administered orally with food, monthly, to dogs in five dose bands at a minimum target dose of 30 mg/kg (see **Table 1**).

## *Metaflumizone*

Metaflumizone is a semicarbazone compound derived from the dihydropyrazole insecticides.[98] Metaflumizone exerts its effects by binding to voltage-dependent sodium channels in target insects. Metaflumizone is related to indoxacarb, an oxadiazine sodium channel-blocking insecticide. Pyrazoline insecticides bind to tonic sensory receptors and pacemaker neurons, which are very sensitive, resulting in insect paralysis. Metaflumizone is the first compound with this unique mode of action to be used in the animal health market. Metaflumizone is marketed alone for cats and is combined with amitraz for flea and tick control in dogs. The minimum target dose of metaflumizone in the feline and canine formulations is 40 mg/kg (see **Table 1**).

### *Permethrin*

Permethrin is a third-generation synthetic pyrethroid that exerts its effect, primarily by modulating gating kinetics of sodium channels in nerves.[91,99] This action results in either repetitive discharges or membrane depolarization and subsequent death of the target arthropod. Recent research also indicates that pyrethroid and permethrin insecticides suppress GABA and glutamate receptor-channel complexes and voltage-activated calcium channels.[97] Permethrin and other synthetic pyrethroids possess quick-kill and contact-repellency effects. Permethrin is the active ingredient in several tick control products (see **Table 1**).

### *Amitraz*

Amitraz is a formamidine compound that exerts its lethal effects by inhibiting mixed function oxidases.[91] Although amitraz is known to inhibit monoamine oxidase, this effect seems to be less important than its effect on mixed function oxidases. Affected ticks show interesting behavioral changes, such as hyperactivity, leg waving, and detachment. These effects are thought to be due the effects of amitraz on octopaminergic G-coupled protein. Other amitraz-induced effects are reduced fecundity, inhibition of oviposition, and diminished egg hatchability. Amitraz has a broad spectrum of activity against various ticks and mites, but it possesses no significant activity against insects. Amitraz in an active ingredient in several tick control products for dogs (see **Table 1**).

## IGRS OR IDIS

Lufenuron, methoprene, pyriproxyfen, and other IGRs or IDIs exert their effects on flea eggs, larvae, or pharate (early) pupae.[72,100–104] They do so by either interfering with the development of chitin or chitinous structures (lufenuron) or by disrupting the hormonal signals necessary for successful development or molting (methoprene, pyriproxyfen). These agents are either administered orally or by injection (lufenuron) or topically (pyriproxyfen, methoprene) and provide long-term (generally 30 days or more) ovicidal and larvicidal effects. Recent products that combine dinotefuran and pyriproxyfen also carry label claims against pharate (early) pupae. The strength of a combination of adulticide and IGRs or IDIs is that they are likely to decrease the time necessary to control flea infestations. This is particularly important in the case of heavy flea infestations or when pet owners are experiencing flea bites. Secondly, when used in combination with adulticidal compounds, the likelihood of developing resistance is diminished considerably, because the flea life cycle is being disrupted at different points and by entirely different mechanisms.

### *Vaccination Against Flea or Ticks*

Vaccination strategies for control of fleas and ticks are based on the induction of antibodies (or other factors) that attack and destroy "concealed" or "hidden" gut antigens.[105–107] These strategies presume that moieties from the midgut of fleas and ticks are not revealed to the host during feeding and engorgement (thus "hidden" antigens). They are isolated, purified, and introduced into target animals, together with adjuvanting substances, to enhance contact with immune competent cells. Although some success has been achieved using these strategies for ticks of production animals[106] and fleas of companion animals,[107] the achieved levels of efficacy, thus far, are not likely to be satisfactory to veterinarians and pet owners. To the best of the authors' knowledge, the availability of commercial tick vaccines to date has been limited to cattle ticks (*Boophilus microplus*), and they are available only in Australia and Cuba. Continued improvements in molecular methods of identification and isolation, and the delivery of putative immunogens, may eventually lead to the development and marketing of such vaccines in dogs and cats. The authors' opinion is that they are more likely to be useful as agents to prevent accumulations of environmental stages of fleas or ticks, given that their principal effects are to reduce engorgement (hence egg-laying) of the female arthropod. They also may be useful in reducing the transmission of arthropod-borne diseases, if the period of feeding and engorgement can be reduced sufficiently.

## SUMMARY

Fleas (*C felis*) are important causes of primary disease (FBD) in dogs and cats. They may also cause allergic skin disease (FAD) and may serve as vectors of bacterial, rickettsial, viral, and parasitic diseases. Adult fleas on animals comprise just 5% of the total flea population. Understanding the life cycle of fleas and the habits of the adult and immature stages are important in successful prevention of flea-associated diseases. Modern host-targeted adulticides or adulticide-IGR combinations are highly effective in treating and preventing on-animal and environmental flea infestations. Ticks are also causes of primary irritation and are effective vectors for important diseases such as Lyme borreliosis, Rocky Mountain spotted fever, ehrlichiosis, anaplasmosis, babesiosis, cytauxzoonosis, and hepatozoonosis. Four genera (eight species) of hard ticks (family Ixodidae) are important ectoparasites in North America. Immature stages of a single soft tick (family Argasidae; *O megnini*) parasitize dogs and cats in North America. Hard ticks that infest dogs and cats are three-host ticks, so named because the different stages (larvae, nymphs, and adults) feed on different individual hosts. Immature ticks usually feed on small mammals (although they will feed on dogs, cats, and humans), birds, or reptiles. Adult ticks are more commonly found on larger mammals, including dogs, cats, and humans. The brown dog tick (*R sanguineus*) is uniquely important because it only requires dogs for completion of its life cycle. Consequently, it can be especially problematic in homes and kennels. Effective tick control is more difficult to achieve than effective flea control, because of the abundance of potential alternative hosts in the tick life cycle. Several effective host-targeted tick control agents are available, also possessing activity against adult or immature fleas and other parasites. Compliant use of host-targeted flea and tick control products, together with a knowledge of flea and tick life cycles, is necessary to control fleas and ticks on the animal, in the home, and in outdoor environments.

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