Tick-transmitted pathogens represent a significant and increasing health challenge for dogs. Transmission of pathogens from an infected tick to a susceptible canine host involves a complex interaction between the mammalian host and the arachnid vector. Understanding the steps involved and the factors affecting each step in the process will help the veterinarian to give the best advice for controlling the risk of infection, preventing clinical disease and reducing the occurrence of subclinically infected carrier dogs. In addition, tick-borne pathogens are frequently zoonotic; therefore, reducing the risk of infection for dogs can also provide a benefit to human populations.

TICKS AND TICK-TRANSMITTED PATHOGENS

Ticks are blood-feeding, ectoparasitic arachnids of vertebrates, primarily mammals, birds and reptiles. There are two families of ticks, the Argasidae - soft bodied, rapid feeding ticks that stay attached to a host for a short period of time, typically a few hours or less – and the Ixodidae. The Ixodidae are hard bodied ticks that require days to complete a feeding and remain firmly attached, usually to a single host, while feeding. The majority of the Ixodidae ticks are in five genera: *Ixodes*, *Amblyomma*, *Dermacentor*, *Rhipicephalus* and *Haemaphysalis*. Ticks in these genera are responsible for transmitting most tick-borne pathogens of significance to veterinary and human medicine. Each tick species within these genera is capable of transmitting multiple pathogens that can infect both dogs and humans, and a single tick may transmit multiple pathogens simultaneously to a mammalian host during one feeding. New tick-borne pathogens such as the Panola Mountain Ehrlichia, *E. muris*, *Borrelia miyamotoi* and the Heartland virus, have all been described in recent years and it is possible that there are additional pathogens that have yet to be discovered.

Ticks have 4 life cycle stages; eggs, larvae, nymphs and adults, and the life cycle from egg to egg can take up to 2 years to complete. Once a tick feeds to completion and detaches from the host, the tick will not feed on a second host unless it molts or was detached prematurely from the first host. The fully fed tick will then take weeks after feeding to continue to the next stage in the life cycle by either molting or laying eggs. Ticks fed to completion rarely establish colonies in homes because indoor humidity is generally too low for the tick to survive long enough to molt or lay viable eggs. In addition, most ticks require an outdoors existence because they depend on a variety of host species to complete their life cycles, including small mammals, reptiles and birds for larval and nymphal life stages, and large mammals such as deer, felids and canids for adult ticks. The exception is the brown dog tick (*R. sanguineus*) which uses dogs as its sole host for larvae, nymphs and adults and is very resistant to drying; therefore, it can survive and complete its life cycle in homes and indoor kennels. When a tick infestation occurs inside a home it is usually the brown dog tick and these infestations can result in large numbers of ticks inside the building.

The tick preference for feeding only once during each developmental stage has an important impact on the mechanics of tick-borne disease transmission. Larvae or nymphal tick stages acquire pathogens while taking a blood meal from an infected vertebrate carrier, which is frequently a rodent. Few tick-borne pathogens are transmitted transovarially, that is from the adult female via the eggs to the larval stage and so most tick-borne infections are transmitted to dogs and humans by nymph or adult ticks. Notable exceptions are the *Rickettsia* spp., agents within the Rocky Mountain spotted fever group of organisms and *Babesia* spp. which can be
transmitted transovarially from adult female to eggs and can be transmitted to vertebrate hosts by larval tick stages.

**DOGS AS SENTINELS AND RESERVOIRS**

Dogs are sentinels for many zoonotic, tick-borne pathogens including the causes of Lyme borreliosis, ehrlichiosis, spotted fever rickettsia and anaplasmosis. Detection of these diseases in the dog population is a clear indication of risk for human populations that may be exposed to attachment by the same ticks as the dogs. However, dogs are not often considered to be a primary reservoir for tick-borne pathogens, with possible exceptions of *Rickettsia conorii*, the causative agent of Mediterranean spotted fever; *E. canis*; and possibly *E. ewingii*. However, dogs can be subclinical carriers for tick-borne pathogens and can maintain active infections for months to years. It is possible that infected dogs could act as reservoirs for tick-borne pathogens including *Ehrlichia chaffeensis*, *E. ewingii*, *Anaplasma phagocytophilum*, *A. platys* and *Rickettsia* spp. Direct transmission of a tick-borne pathogen from dog to human is highly unlikely; however, pet owners, veterinarians or animal care workers can become contaminated with tick borne pathogens when removing engorged ticks from carrier animals. Failure to exercise appropriate hand washing following engorged tick removal could create a risk. Rickettsial pathogen inoculation can occur through mucus membranes after introduction via contaminated fingers. Veterinarians testing clinically affected dogs report detecting evidence of tick-borne pathogen infection, illustrating the continuing risk of infection and the need for veterinarians to be aware of the potential for tick-borne disease transfer. Effective tick control for dogs will dramatically reduce this potential risk.

**TICK FEEDING**

The process by which a tick selects a host, migrates onto the host, attaches and then feeds involves a complex interaction between the tick and the host. The questing tick detects a host through warmth, vibrations, shadows, and elevated CO2 ([http://www.cdc.gov/ticks/life_cycle_and_hosts.html#find](http://www.cdc.gov/ticks/life_cycle_and_hosts.html#find)). After catching onto the hair coat of a passing dog, the tick may immediately attach, or it may take some time to migrate to a preferred attachment site. Different tick genera appear to have selective preferences for the time that they take to find an attachment site.

Once the tick has selected an attachment site, the process of penetrating the host skin and cementing itself in place takes additional time. The tick cuts through the skin with its cheliceral bundles and then inserts its ratchet-shaped hypostome that will serve as the conduit for deposition of saliva and then intake of host fluids.

Once its mouth parts are in place, the tick secretes saliva from salivary glands through its mouth parts into the host skin wound. The salivary secretions may contain a cement that firmly attaches the mouth parts to the host attachment site. Tick saliva contains multiple other bioactive compounds including analgesic substances that anesthetize the site of attachment. The anesthetic effect serves to prolong the feeding time available to the tick by reducing the risk that the host will be stimulated by local irritation to scratch at the site and potentially remove the tick. Tick saliva also contains compounds that modulate the host immune response, dilate local vasculature and inhibit blood coagulation. If host blood coagulated, this would reduce the ability of the tick to feed by potentially obstructing the tick mouthparts. The tick also secretes substances that alter the effectiveness of the host immune-response and may have other impacts on host immune system activity, for example red meat allergy has been reported in people following repeated exposure to tick bites. The presence of the tick also elicits local host immune-responses that result in increased blood flow to the site and promote neovascularization. The feeding tick ingests subcutaneous tissue fluids and blood, while
intermittently secreting saliva into the wound. The salivary secretions allow the tick to prolong feeding and make its feeding more effective by concentrating blood nutrients and eliminating excess water and ions. Up to 50% of the fluid ingested by the tick is returned to the host via salivary gland secretions. During the repeated salivary injection into the host over the tick feeding process any pathogens present in tick salivary glands will be inoculated into the host. As discussed later in this paper, the process of feeding leads to changes in the pathogen population in the tick, and direct inoculation of pathogens found in tick saliva is the most efficient mechanism of transmission of tick-borne pathogens. A second method of tick borne pathogen spread is through exposure of the host to tick fecal excretions. While blood feeding, the tick produces pathogen contaminated fecal excretions that are deposited around the tick bite site. Pathogens from tick feces may enter the tick bite wound or possibly enter other skin wounds in the area. People may also infect themselves by transferring pathogens on fingers that have scratched at the site of tick attachment to mucus membranes.

TICK ACQUISITION OF PATHOGENS
Ticks acquire their infections during a blood meal on an infected vertebrate host. Some of these hosts, particularly wild-life such as deer and rodents, are subclinically infected carriers that are natural reservoirs for the infections. *Borrelia burgdorferi* prevalence was as high as 21% in *Peromyscus* spp. mice trapped in New York State, and 33% of nymph and 55% of adult ticks were spirochete positive in a study of ticks near the home of people with Lyme disease. Dogs and humans are considered incidental hosts for most tick-borne infections, but there is concern that increasing exposure of dogs to ticks could contribute to the overall pathogen burden. Ticks may also acquire infections while feeding on a previously uninfected vertebrate host by feeding in close proximity (within 1 cm) to another infected tick and ingesting pathogens that enter host subcutaneous fluids from the secretions of the other infected ticks. This method of transmission is known as “co-feeding” and can significantly increase the pathogen burden in the tick population. Co-feeding pathogen transmission is enhanced by the tendency for various stages and species of ticks to preferentially feed on certain areas on the body of the host such as the ears, face and feet. For example, over 90% of immature stages of *I. ricinus* ticks were found to preferentially select the ears of rodents as an attachment site. Pathogen transmission between ticks by co-feeding does not require both ticks to be feeding simultaneously and a tick may become infected by attaching to the area where an infected tick was previously feeding.

THE PATHOGEN IN THE TICK
Once ingested by the tick, pathogens must adapt to extreme environments, including fluctuations in temperature and humidity, and prolonged periods when the tick does not feed. The pathogen may become dormant within the tick to survive the conditions between blood meals. When the tick begins to ingest another blood meal, the pathogen needs to reactivate, a process which may include: replication, physical alteration, maturation and relocation from the tick midgut to the ovaries and salivary glands. It has been shown that pathogen movement from the tick midgut to the salivary tissue does not occur until after the tick re-attaches to a vertebrate host and starts to feed. Replication and relocation must lead to the presence of a sufficient number of pathogens in the tick salivary glands to create an “infective dose” before transmission to the host occurs. The time required for this pathogen reactivation process is a significant component of the “grace period” observed between the start of tick attachment and subsequent infection of the host. This grace period provides an important window of opportunity to prevent pathogen transmission by killing the tick through systemic acaricidal treatment, topical acaricide application or manual tick removal. Pathogen behavior has an impact on the speed of host infection during initial tick feeding. Pathogens that infect tick mononuclear cells, such as *Ehrlichia* spp., *Anaplasma* spp. and *Rickettsia* spp., can move more rapidly inside the tick through transport in tick hemolymph. Pathogens that move by migration (e.g. *Borrelia* spp.) tend
to travel through tick tissues more slowly and may take longer to reach an infective dose in the salivary glands. Some pathogens may be present in the salivary glands of ticks at the time of feeding whereas others (B. burgdorferi) are not found in salivary tissue during initial tick attachment but can be found in dramatically increased numbers 72 hours later. Pathogens that disseminate more rapidly in the tick are likely to infect the host more quickly after tick attachment.

TRANSMISSION TIMES

There is a delay between the time of tick attachment and pathogen transmission into the host, although this time may vary from organism to organism and tick species to tick species. This “grace period” provides an opportunity to prevent disease transmission to people and pets via use of systemic or topical acaricides and appropriate and timely tick removal.

There are multiple factors that can affect the length of time a tick must be attached in order to effectively transmit a pathogen. These include the reactivation process of the organism, the tick species and life stage (nymph vs. adult), the environmental temperature and the type of vertebrate host. Therefore, transmission times for each pathogen can vary considerably and cannot be accurately predicted in any specific situation. However, it is generally thought that transmission times for Babesia spp. and Borrelia spp. are longer than transmission times for Ehrlichia spp. Anaplasma spp. or Rickettsia spp. Under experimental conditions I. scapularis ticks need to feed for 24 to 48 hours to ensure effective transmission of B. burgdorferi. However, this feeding time may not be required under all circumstances and I. ricinus has been shown to transmit B. burgdorferi or B. afzelii in less than 24 hours. In addition, under experimental conditions, partially fed I. scapularis ticks transmitted B. burgdorferi in well under 24 hours when they reattached to a second vertebrate host. It is predicted that Babesia canis canis sporozoites are not transmitted by the tick until 48 hours or more after tick attachment.

Studies in dogs with Rickettsia spp., Anaplasma spp. and Ehrlichia spp. also indicate that transmission times can be less than 24 hours and Rhipicephalus sanguineous transmitted E. canis organisms to dogs within 3 hours of tick attachment. In general, however, most studies indicate that 12-18 hours of tick attachment are required to effectively transmit pathogens, and longer times are typically required for Borrelia spp.

Two additional points need to be considered. The first is that experimental work has shown that an interrupted feeding nymph tick will seek another blood meal. Pathogen activation has already occurred during initial tick feeding and transmission time is more rapid upon reattachment to a new host. The risk of this phenomenon occurring in the natural situation is not clear. A second consideration is that manipulation of a feeding tick during human efforts to detach the tick could increase the risk of pathogen injection.

TICK-BORNE DISEASES CREATE CONCERNS FOR OWNER AND VETERINARIANS

Veterinarians and animal health care workers are occupationally at risk for the development of arthropod-borne diseases from exposure to fleas, ticks, lice and the host animals that harbor them. Potential routes of pathogen exposure include scratches, bite wounds and transmission through the bite of an infected arthropod vector. Bites and scratch wounds from cats are a particularly dangerous source of exposure to Bartonella spp. Dogs are prone to acquiring ticks because of their long hair and because they walk on all four limbs with their body in close proximity to the ground. Ticks may also be more difficult to identify on a dog because of the opportunity for ticks to hide in the hair coat and because of the small size of some tick genera and life stages.

Difficulties in diagnosing and treating tick-borne disease in dogs underline the importance of effective tick protection. The clinical signs of tick-borne disease in dogs can be vague, and may be misdiagnosed since they may be seen with a host of other disorders. The most common
clinical and clinicopathological abnormalities seen in dogs infected with a tick-borne pathogen include: persistent, unexplained fever; shifting leg lameness; lymphadenopathy; splenomegaly; thrombocytopenia; anemia; and, hyperglobulinemia.

PREVENTION
Dog owners and veterinarians must work together to provide effective tick control, including behavioral changes, therapeutic measures and vaccination against tick-borne diseases where available. Effective tick control not only reduces the presence of ticks on companion animals, it also reduces the risk of tick-borne diseases, anemia, tick bite related immune disorders, tick bite paralysis, tick bite infection and attachment site irritation for the pet. Behavior modification is very important for reducing exposure to ticks, and offers potentially the greatest benefit for the cost incurred. This includes limiting, when possible, the time spent in known tick infested areas. People engaging in activities that put them at risk for tick exposure should wear appropriate protective clothing, potentially with tick repellent impregnated fabric, and use repellents and acaricides. People should examine themselves and their dogs for ticks on skin or clothing after engaging in at-risk activities such as camping, hiking hunting or jogging in areas where ticks are known to occur. As shown above, the grace period between tick attachment and pathogen transmission provides an opportunity to remove the tick before transmission of a tick-borne infection. However, people love to get out with their dogs, and although behavior modification is vital, there will always be a risk for dogs and people of exposure to questing ticks. Therefore, therapeutic options continue to be necessary. Dogs can benefit from both systemically and topically administered acaricides and repellents. There are three important considerations in considering tick control options: 1. Owner compliance with the treatment recommendations; 2. A speed of tick kill that stops tick feeding before the pathogen transmission grace period ends; and, 3. efficacy throughout the retreatment interval. Repellents are less effective in controlling tick attacks than they are for other biting arthropods such as mosquitoes, sandflies and fleas. Acaricides appear to offer greater efficacy and can be administered systemically or topically. Recent data on a systemically administered acaricide has shown the potential for high efficacy throughout the treatment interval. The active ingredient(s) in topical acaricides and collars is deposited on the skin surface and typically then needs to disperse to be located where the interaction between tick and vertebrate host occurs. Tick attachments have been recorded following recommended use of topical treatments and adequate dispersion of the active ingredient or subsequent wash-off can be concerns. Field experience with topical treatments also suggests that efficacy may not be as consistent and long lasting as seen under experimental conditions, perhaps because patterns of dog behavior and movement, application failures and lack of owner compliance with treatment administration recommendations.

A concern with systemic acaricides is that the tick needs to bite in order to be exposed to the active ingredient. However, recent introduction of highly effective systemic acaricides is leading to reconsideration of this option for reducing exposure to tick borne disease and in fact systemic acaracides have been show to effectively block transmission of B. canis by Dermacentor reticulatus ticks in dogs. These products offer a new option for improvements in all three areas related to tick control: owner compliance, rapid speed of tick kill, and prolonged efficacy duration, reducing the potential for monthly gaps in protection. There are still many aspects of the mechanisms regarding inhibition of pathogen transmission that are unknown. Further understanding of the complex interactions that occur during tick attachment and feeding, and the pathogen developmental processes that must occur following attachment, will help in the development and administration of effective acaricides that prevent transmission of an infectious dose of viable pathogens. It is certainly possible that the use of systemic acaricides will have a sufficiently negative impact on tick feeding mechanisms so as to prevent pathogen transmission, even if the tick initially attaches. At this time it is not possible to
completely prevent tick-borne disease transmission under field conditions; however, owners and veterinarians are advised to use the optimal acaricidal options available. In addition, use of Lyme disease vaccination is also recommended to prepare the immune system of the dog before exposure to *Borrelia burgdorferi*. It is hoped that vaccinations will be available for additional tick-borne pathogens in the future.

**SUMMARY**
Stopping the spread of vectors and vector-borne diseases in people and pets is a vital role in the practice of veterinary medicine. Understanding vector biology, particularly with regard to pathogen transmission is crucial to disease prevention. Limiting ticks on pets reduces the pathogen burden in the environment and reduces exposure to both people and pets, particularly dogs. Behavioral changes, use of effective treatments and vaccination are recommended for reducing the risk of tick-borne disease.