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Current Control Strategies to Combat Lyme Disease in the North-Central and Eastern U.S.

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Abstract: Lyme disease is an emerging infectious disease accounting for more than 90% of all reported vector-borne diseases in the United States. In the eastern U.S., the deer tick *Ixodes scapularis* carries the spirochete *Borrelia burgdorferi*, which causes the disease. The main reservoir for the spirochete in the wild is the white-footed mouse *Peromyscus leucopus,* which serves as the most common blood-meal host for the larval and nymphal life stages of the tick. Additionally, the enzootic cycle includes the white-tailed deer *Odocoileus virginianus.* As the human incidence of Lyme disease continues to increase, effective intervention methods are needed. Control methods for decreasing risk of contracting Lyme disease have been developed and center on targeting the tick or the wildlife hosts that harbor the tick vector. Personal protective measures have also been developed to protect individuals potentially exposed.

Key Words: zoonosis, public health, Lyme disease, *Borrelia burgdorferi*, white-footed mouse, *Peromyscus leucopus*, white-tailed deer, *Odocoileus virginianus*, deer tick, *Ixodes scapularis*

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INTRODUCTION

Considered an Emerging Infectious Disease by the CDC, human Lyme disease cases in the United States have increased about 25-fold since national surveillance began in 1982. The yearly average number of human cases reported is approximately 16,000 (CDC 2002a). The incidence of the disease is increasing; the number of cases in the year 2000 was greater than 17,000, the most of any year reported. Between 1991 and 2000, the reported incidence has almost doubled (CDC 2002b). The CDC reports that Lyme disease accounts for more than 95% of all reported vector-borne illnesses in the U.S., and more than 145,000 human cases have been reported to health authorities (CDC 2002c). The disease is primarily localized to states in the northeastern, mid-Atlantic, and upper north-central regions and to several areas in northwestern California (Dennis 1998). This paper discusses the Lyme disease cycle and strategies to control human infections in the north-central and eastern portions of the U.S.

In the eastern United States, the deer tick *Ixodes scapularis* is implicated in the transfer of the spirochete to humans. This tick is in a 2-year enzootic cycle with small mammals and deer, with the most common hosts being the white-footed mouse, *Peromyscus leucopus* and the white-tailed deer, *Odocoileus virginianus*.

ENZOOTIC CYCLE OF LYME DISEASE

As summarized in Sigal (1993), the 2-year life cycle of *I. scapularis* cycle begins when larvae hatch spirochete free in the summer (Figure 1). The larval ticks feed on small mammals in the summer and fall (July-September). The white-footed mouse is the most common host at this point. If the host is infected with *B. burgdorferi*, the larvae have the opportunity to acquire the infection. After feeding, the larvae remain dormant over winter, and the following spring they molt into nymphs and begin questing to feed. The spring and summer (May-July) are the primary months when nymphs seek a host for feeding, and it is the most common time for humans to become infected. If the nymphs are infected, then spirochete transfer to a host can occur. The most common host at this feeding is, again, the white-footed mouse. After feeding, the nymphs drop to the ground and molt into adults. In the fall of the same year, the adults seek an additional blood meal, and infection to human hosts can occur here as well. At this point, the adult ticks seek larger hosts, because they are questing at higher (~1 m) levels in the foliage. The most common host at this feeding is the white-tailed deer, and it is during this blood meal that the adult ticks breed. Following the adult blood meal in the fall, the adult ticks drop to the ground, remain dormant in the winter, and the females emerge in the spring to lay eggs. The female ticks die after laying eggs.

Humans acquire *B. burgdorferi* infection from infected ticks at the time the tick takes a blood meal (Piesman 1993). This nymphal stage of the tick is responsible for nearly 90% of Lyme disease cases each year (Fish 1993). As nymphs, the ticks are very small and difficult to detect. Studies have shown that it takes at least 24-48 hours for inoculation to the host to occur (Falco et al. 1996).

Although deer are not competent reservoirs of *B. burgdorferi*, they are the principal maintenance hosts for adult deer ticks, and the presence of deer appears to be a prerequisite for the establishment of *I. scapularis* in any area (Wilson et al. 1985). The rapid repopulation of white-tailed deer in the eastern United States in the recent decades has been linked to the spread of *I. scapularis* ticks and of Lyme disease in this region, and the future

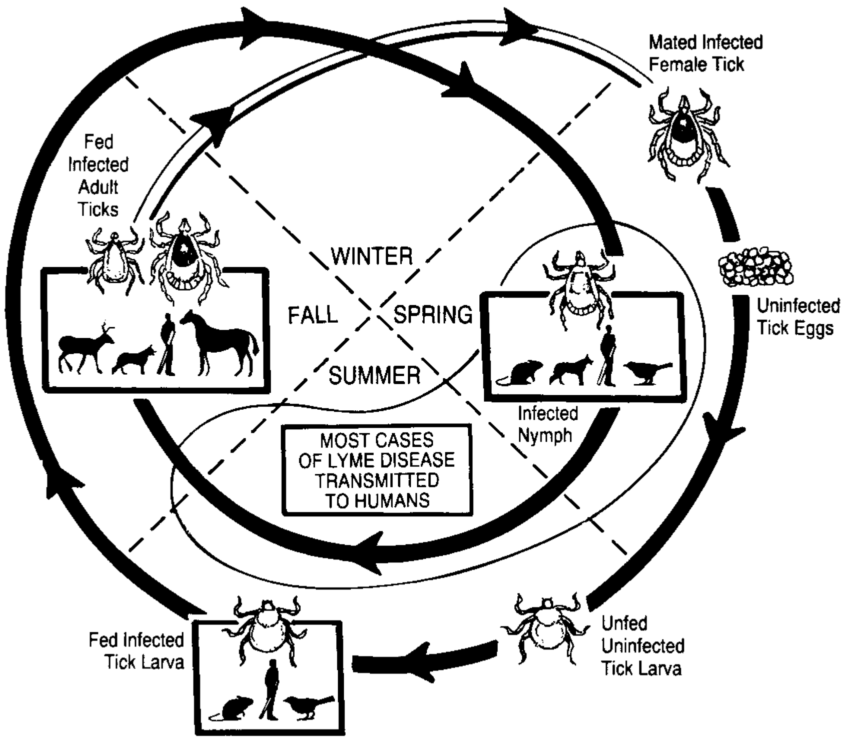

Figure 1. The life cycle of *Ixodes scapularis* in relation to its role as a vector of Lyme disease (Sigal 1993).

limits of this proliferation are yet to be determined (Wilson 1998). In areas of the northeast, deforestation and urbanization have resulted in increases in population of wildlife, including deer, which has caused enhanced transmission of Lyme disease to humans (Lane and Anderson 2001).

The risk of human exposure to Lyme disease is a function of the local abundance of nymph and adult ticks (Stafford et al. 1998) and is strongly correlated with the density of spirochete-infected ticks in the areas surrounding residences (Mather et al. 1996). Caraco et al. (1998) modeled the transmission ecology of *B. burgdorferi* and concur, via their modeling, that the risk of Lyme disease in humans increases with the density of infected nymphs. The abundance of infected nymphs increases by the abundance of larval ticks and susceptibility of mice and larval ticks to infection. The highest risk of humans acquiring Lyme disease is in peridomestic areas, which are typically the areas around the home and on the fringe areas of forest (Maupin et al. 1991).

CONTROL METHODS

Control strategies currently practiced in the U.S. for Lyme disease center on tick host reduction, habitat modification, and chemical application. Other current recommendations advise the use of repellents, administration of a vaccine, and recommending that individuals avoid entering tick-infested areas. Control attempts can be divided into two types: ecological approaches and personal protection.

Methods Targeting the Tick

Ecological approaches involve some manipulation of the species involved in the enzootic cycle of the disease. Insecticides, applied to areas of tick infestation, have been used successfully to reduce the abundance of ticks and Lyme disease risk in local areas and individual properties. *I. scapularis* is susceptible to many synthetic and natural insecticides (Maupin and Piesman 1994, Panella et al. 1997). Initial studies sought to control *I. scapularis* by low-pressure spraying liquid formulations of diazinon, an organophosphate insecticide and carbaryl, a carbamate insecticide. This method decreased area adult populations by greater than 90% but was unsuccessful in controlling the other life stages of the tick (Schulze et al. 1987). Sub-adult control is more difficult because liquid formulations have a difficult time penetrating the low level vegetation at which sub-adult ticks reside. Because most applications available to the homeowner are low pressure, e.g., commercially available sprays, homeowner application is typically not effective. High pressure spraying of carbaryl was later attempted and was effective against all life stages of the tick, but treatment did not last long in woodland areas and high grass because of decreased penetration of the insecticide into the leaf litter. The treatment was most effective on lawn areas (Stafford 1991a). High-pressure spraying requires equipment to which only certified applicators have access. Granular insecticide formulations have also been tested for tick control. Granular carbaryl reduced the number of *I. scapularis* nymphs on white-footed mice in areas of use when applied at nymphal peaks. However, in areas of abundant leaf litter, granular formulations also have diminished effectiveness because of lack of penetration, and the effectiveness of acaricide use can also be diminished if adjacent areas provide suitable habitat for either *I. scapularis* or *P. leucopus* (Schulze et al. 1994). Although it is clear that the use of area-wide acaricide treatment may have some effect on tick populations, environmental hazards associated with the use of insecticides and effects on non-target organisms severely limit the usefulness of such application of these products (Gage et al. 1995, Panella et al. 1997). A recent article in a pest control industry trade journal recommended only acaricide application for control of deer ticks on lawns and woodlands (Goddard 2001). Yet, pesticide use by licensed applicators for the control of *I. scapularis* in Connecticut comprised less than 5% of their overall business, with only 3 chemicals being used: chlorpyrifos, cyfluthrin, and carbaryl (Stafford 1997). Commercial tick control is not widespread.

Other methods of tick control involve the manipulation of habitat. Schulze et al. (1995) found that the manual removal of leaf litter, using rakes and leaf blowers, in late spring and early summer decreased nymphal and larval tick abundance. Wilson (1986) found that the mowing of understory vegetation reduced tick abundance for 12 months. Mather et al. (1996) and Stafford et al. (1998) investigated the use of controlled burning of vegetation to reduce tick habitat. Burning was found to reduce the presence of host-seeking ticks in the same season of burning. Control methods via leaf litter removal though have been unpredictable and may actually lead to an increase in tick abundance, because burning can improve deer browse and the density of *Peromyscus* spp. The use of nematodes as biocontrol agents to control the developmental stages of *I. scapularis* has been investigated but has not been tested in the field (Hill 1998).

Methods Targeting Wildlife

Methods focusing on wildlife have targeted the wildlife hosts of *I. scapularis*. To decrease small mammal tick burden, a commercially available product was developed (Damminix, Ecohealth, Boston, MA) in which permethrin-impregnated cotton is presented in small dispensers that are placed in areas of small mammal usage. The product was designed to attract mice to the cotton as nesting material. The insecticide-impregnated cotton would then control the ticks on the mouse (Deblinger and Rimmer 1991, Stafford 1991b). Mice readily harvested the cotton, and a decrease in tick abundance on mice was observed. The overall success of this method in reducing the amount of ticks infesting mice has been limited (Gage et al. 1995) and the status of the commercially available product is unknown. Control of ticks as well as fleas has also been accomplished via the application of liquid permethrin by attracting rodents into a tube that applied the insecticide to their backs (Gage et al. 1997). Patrican and Allan (1995) reported significant control on nymphal and adult *I. scapularis* using a desiccant and a insecticidal soap each containing pyrethrum. This approach was successful in the short-term in reducing populations of ticks but lacked residual activity. The management of small mammal host populations via rodenticides has not been evaluated. Rodenticides would likely be inefficient in preventing Lyme disease, because there is great diversity of hosts in Lyme disease foci and because the control of the small and medium-sized vertebrates that are hosts for juvenile ticks is neither practical nor desirable in many cases (Gage et al. 1995).

Methods targeting the white-tailed deer have been attempted as well. Wilson et al. (1988) found that the removal of deer by hunting decreased larval tick abundance, which was an indication that without the presence of deer, adult ticks failed to obtain a blood meal and reproduce. The near elimination of the herd had the greatest effect. Incremental removal of deer over 7 years has a similar effect on tick reduction (Deblinger et al. 1993). Stafford (1993) found that the removal of deer by electric fencing decreased the number of host-seeking nymphal and larval ticks.

Application of an acaricide to deer using self-applicators is a recent development in Lyme disease control. The burden of adult *I. scapularis* on white-tailed deer was decreased using permethrin via a self-applicator that applies insecticide to deer through a porous cylindrical ceramic column as they feed (Sonenshine et al. 1996). A similar device currently under investigation is called the "4-poster" apparatus, which baits wild deer into a feeding station causing contact with paint rollers, allowing the application of pesticide to the sides of the deer (Pound et al. 1996). The apparatus has been previously used to decrease the burden of lone star ticks *Amblyomma americanum* on white-tailed deer using the pesticide amitraz (Pound et al. 2000). The U.S. Department of Agriculture is currently performing a 5-year study to determine the effectiveness of this device against adult *I. scapularis* burden on white-tailed deer as well as the density of free host-seeking nymph populations. The results of this multiple-year study are still pending (USDA 1999 and pers. comm., J. Matthews Pound, USDA-ARS, Kerrville, TX).

Human Interventions

The second approach to lowering the risk of Lyme disease in humans involves personal protection. Personal protection is necessary for any individuals including homeowners, children, wildlife biologists, and park managers. The easiest forms of personal protection involve not entering tick-infested areas, the use of protective clothing (light colored long-sleeve shirts, tucking pant-legs into socks), the use of repellents and acaricides, and checking for ticks after entering potential tick infested areas (CDC 1999). Pressurized sprays are available containing permethrin or DEET (*N,N*-diethyl-*m*-toluamide). DEET is sprayed onto clothing and repels ticks rather than kills them, but it can be toxic to persons using the product if used for too long a duration. Permethrin is an acaricide that is applied to clothes, but it is a risk to humans because it is a suspected carcinogen (Barbour 1996). Personal protection was also available via a vaccine called LYMErix by SmithKline Beechem, for use in humans. The CDC had recommended the vaccine for individuals 15-70 years old who have the possibility of exposure to the bacteria. Unfortunately, citing poor sales and lack of demand, the producer has discontinued the vaccine from the market (Anonymous 2002).

DISCUSSION

The control of Lyme disease centers on approaches that target the tick vector of the disease, the wildlife host of the tick vector, or personal protection. Integrated Pest Management (IPM) approaches could be utilized to control the tick vector of the disease. Bloemer et al. (1990) developed an IPM approach to management of the lone star tick in recreational areas using acaricide application, vegetative management, and exclusion of white-tailed deer. Between 89% and 96% control was achieved at a cost between \$30 and \$150/hectare. Ginsberg (2001) found that integrating two or more control techniques that have the same effect is likely to be more effective than combined use of techniques that have different effects. Control efforts for Lyme disease could concentrate on the reduction of *I. scapularis* ticks, since risk is associated with density of infected ticks in an area. Incorporating many approaches to tick control could lower the risk of this disease to individuals in Lyme disease-endemic areas. As evidenced by the increase in the incidence of Lyme disease in the year 2000 and the discontinuation of the only available Lyme disease vaccine from the market, effective control strategies for this debilitating disease are needed now more than ever.

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