Military Veteran Residential Location and Risk for Lyme Disease

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Abstract

Some research has shown that Lyme disease cases among United States (U.S.) military veterans have increased since the early 2000s. The purpose of this study is to determine whether high concentrations of military veterans live in areas where Lyme disease is hyper-endemic. Lyme disease case-report data for 2015 were retrieved at the county-level from the Centers for Disease Control and Prevention. Veteran population density at the county level was determined using data from the U.S. Census. County control variables, such as weather patterns, forestation, and socioeconomic conditions were retrieved from various sources. Multiple linear regression was used to examine associations between variables. After controlling for county-level environmental and social conditions, results showed that military veteran population density was positively associated with Lyme disease incidence rates. U.S. military veterans, due to their choice of geographic residence and recreation, may be a population at risk for developing Lyme disease.

Keywords: Lyme disease, U.S. military veterans, public health, epidemiology

Introduction

Vector borne diseases, particularly those spread by various species of ticks, have become a major public health issue throughout the world (1). Except for mosquitoes, ticks are considered the primary sources of vector borne disease in most countries, but especially those in North America (2-5). In this area of the world, there are approximately 15 tick species currently known to be capable of causing disease in humans and animals (6). In fact, the problem has grown to the extent that tick-borne diseases are considered the most commonly reported vector-borne disease (2,4). When it comes to the U.S., the majority of human infections are caused by only three genera of ticks belonging to the *Ixodidae* family: *Ixodes, Amblyomma*, and *Dermacentor* (4). According to the United States Army Center for Health Promotion and Preventive Medicine (7), in the U.S., *Dermacentor variabilis, Ixodes scapularis,* and *Amblyomma americanum* are the primary vectors of concern, since they spread most of the microorganisms capable of infecting humans. Unfortunately, many researchers (8-10) have demonstrated that, within the last few decades, the prevalence of tick-borne disease (TBDs) has increased significantly.

During the 1970s, only two tick-borne diseases (TBDs) were of concern to human health: Rocky Mountain spotted fever and Colorado tick fever (11,12). Since then there has been an emergence and reemergence of TBDs, many of which have the potential to cause severe illness or even death (2,13). According to the Centers for Disease Control and Prevention (CDC) (14), there are currently 16 TBDs known to exist in the U.S. While the number of cases for all TBDs has increased, the most frequently contracted is *Lyme borreliosis* (15,16).

Literature Review

Commonly referred to as Lyme disease, *Lyme borreliosis* was initially discovered in Lyme, Connecticut, in 1976. During that time, 24 children developed what physicians originally believed to

be a juvenile form of rheumatoid arthritis (17). These cases were unique in the fact that shortly before the onset of this unusual condition, the majority of stricken children exhibited a rash resembling a bull's eye. This prompted doctors to suggest the possibility of a link between the arthritic symptoms and the bite of an arthropod (17,18).

In the early 1980s, researchers ascertained that the causative agent was a spirochete, subsequently named *Borrelia burgdorferi sensu lato* (16,17,19). Further investigations led to the discovery that *B. burgdorferi* was comprised of several genospecies (4,13,17,20). While there are 19 genospecies known to exist throughout the world, only eight are known to cause human disease (21). According to the CDC (14), there are only two genospecies capable of causing illness in humans in the U.S.: *B. Burgdorferi ss* and *B. mayonii*. Franke and colleagues (21), on the other hand, state that two additional genospecies can be found in the U.S.: *B. kurtenbachii* and *B. bissetti*. To date, the vast majority of infections have been caused by *B. burgdorferi s.s.* (16).

While many researchers and physicians originally believed that *Borrelia* subspecies were transmitted through arthropod bites, the causative agent was not isolated from an *Ixodes* tick until 1982, providing definitive evidence that the infectious microorganism was transmitted by an arthropod vector (17). Through extensive field investigations, these individuals concluded that *Ixodes scapularis*, commonly referred to as the deer tick or blacklegged tick, served as the main vector east of the Rocky Mountains; whereas in areas west of the Rocky Mountains, *Ixodes pacificus* (also known as the western black-legged tick) was the responsible vector (16,17,22).

At the time of its initial discovery, Lyme disease was only known to exist in three distinct areas: along the middle and northern portions of the East coast, throughout the upper Midwest, and in the Northern part of the West coast (18). Since being first discovered, this disease has steadily increased in geographical range and can now be found in all fifty states and most countries (4,13,21,23-25). However, the incidence rate is considerably greater in geographical locations (13) that have ample food resources, reservoir hosts, and appropriate temperature and humidity levels capable of supporting the existence of the ticks (6).

In 1982, the CDC created a surveillance program to monitor the incidence of Lyme disease. The baseline case count for Lyme disease in 1982 was 1000 (26,27). Owing, in part, to the sharp increase in the number of human infections over the next few years, Lyme borreliosis became a nationally reportable disease in 1991 (13, 27). So far, the highest annual incidence occurred in 2009, during which there were 29,959 confirmed cases (28). Since then, the number of confirmed infections has ranged from a low of 22,014 cases in 2012 to a high of 28,453 in 2015 (29). However, according to the CDC (29), even though Lyme disease is a reportable infection, not all cases are actually reported. As a result, researchers estimate that the true number of annual cases is closer to 300,000 (29, 30).

This risk for contracting *Lyme borreliosis* increases as the amount of time spent in areas such as tall grass prairies and wooded areas increases (6,24). Although anyone has the potential of becoming infected, certain occupations place individuals at an increased risk of becoming infected (31). One group of individuals that are particularly at risk, because of their occupation and choice of recreational activities, are those serving in the armed forces as well as the veteran population employed on military bases (32,33). According to Hurt and Dorsey (34), the increased risk observed for military personnel can be attributed to the fact that training drills are typically conducted either in or next to locations that are known to harbor a variety of tick species (e.g. woodlands or grasslands). Additionally, military veterans are at risk mainly because they often engage in outdoor activities as part of their on-base occupation, rehabilitation programs, and/or leisure activities (35).

Due to the noted increased risk for Lyme disease among military-connected persons, the Tick-Borne Disease Laboratory of the U.S. Army Center for Health Promotion and Preventive Medicine developed the Human Tick Test Kit Program in 1989 to assess the danger of contracting TBDs on military bases located throughout the U.S. (36, 37). This program allowed physicians working at VA facilities access to free testing services capable of ascertaining whether ticks removed from individuals serving in or retired from the armed forces and their families were infected with *B. burgdorferi* (37). Recent updates to the test kit have allowed for the testing of several tick-borne pathogens, including but not limited to, Ehrlichiosis, Anaplasmosis, and Rocky Mountain spotted fever, in order to assess the true risk of TBDs on military bases around the country (37, 38). It should be noted, however, that this testing only indicates the actual risk based on whether the tick itself is a carrier of an infectious disease and does not provide the number of actual cases of TBD observed among those in the military or their beneficiaries (37).

For reporting of actual cases of TBD, the Disease Reporting System Internet (DRSi) was developed in 2008 by the Navy Marine Corps Public Health Center. This system is utilized by all branches of the military and compiles data on the number of tick-borne disease cases for both active duty military and others who utilize Military Health Services (35). According to Garcia et al. (32), there was a gradual increase in the number of cases observed in personnel from every branch of service during the early 2000s. In fact, from 2005 to 2014, there were between 489 and 934 total cases (active duty and retired members of the military and their dependents) of Lyme disease observed annually at Military Health Services throughout the country, with the highest total number of cases among veterans and dependents occurring in 2008 (35).

Purpose

The purpose of the present study was to evaluate the relationship between veteran population composition and Lyme disease incidence rates at the county level in the U.S. in 2015, after adjusting the aforementioned relationship for historically validated predictors of Lyme disease, such as middle and upper socioeconomic status (e.g., relatively high income and educational attainment) (19) and environmental conditions, such as summer temperatures, rainfall, and forestation (6). In order to assess the aforementioned relationships, constructs – such as social and environmental conditions– were operationalized. Social conditions were defined by whether a county was urban or rural, educational attainment, and household income. Environmental conditions were defined by temperature patterns, precipitation patterns, and the extent of forestation.

Methods

Data Collection

Secondary data at the county-level in the U.S. were retrieved from several sources for the present ecological study. First, Lyme disease cases reported in 2015 were retrieved from the CDC (39). Lyme disease incidence rates per 100,000 were calculated by combining the Lyme disease case data with county population estimates generated by the United States Census Bureau (USCB) in 2015 (40). County-level veteran population data–from 2015–was obtained from the United States Department of Veterans Affairs (41). So as to discern veteran population composition in each county (VET), total veteran population estimates at the county level were divided by total population (POP) estimates–obtained from the USCB–at the county level.

Second, rurality was assessed by retrieving 2013 Rural-Urban Continuum Codes from the United States Department of Agriculture (42). The United States Department of Agriculture (USDA) assigned counties in the U.S. a code between one and nine in 2013, where a code of one

indicated an urban environment with a population of at least 1,000,000 and a code of nine indicated a rural environment with a population less than 2,500. Educational attainment was measured by obtaining–from the USDA–the percent of the population, aged 25 or older, without a high school education in 2015 (43). Household income was measured by obtaining–from the USCB–the median household income for counties in 2015 (44). Forestation was measured by obtaining–from the USDA Forest Service–the number of forested acres in a county and the number of total acres in a county (45); subsequently, the aforementioned variables were used to calculate the percent of forested area in a county in 2015.

All weather data were obtained from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (46). Because the life cycle of the "black legged tick," *Ixodes scapularis*, is two years in North America, weather data were lagged two years relative to Lyme disease incidence rates (47, 48). Specifically, average temperatures (in Fahrenheit) for the month of June 2013 were obtained for all weather stations in the U.S. with at least 15 days of data, as summer temperatures have been shown to correlate with tick abundance (49). Total precipitation (in inches) for the month of June 2013 was obtained for all weather stations in the U.S. with at least 15 days of data, as summer precipitation has been shown to correlate with tick abundance (49). Aggregation of weather station data to the county level ensued in accordance with Barreca and Shimshack's (50) procedure. Specifically, data from all weather stations within 50 miles of each county's geographic centroid–not to exceed the county's border–were included in a calculation of an arithmetic mean of temperature or precipitation.

Data Analysis

First, a choropleth map was created with 2015 USCB county boundaries (51) in QGIS version 2.14 (52) to represent the geographic distribution of Lyme disease incidence rates in 2015. Second, means and standard deviations were calculated for each variable in the study at the USCB regional level (53), as research has shown that Lyme disease has clustered–historically–in the northeastern and upper Midwestern regions of the U.S. (54).

Third, hierarchical ordinary least squares (OLS) multiple regression analysis was carried out (55), where Lyme disease incidence rates per 100,000 were regressed on the following independent variables: rurality, educational attainment, median household income, June temperatures (t–2 years), June precipitation (t–2 years), forestation, total county population, and veteran composition. In the second block of the analysis, a second order polynomial was added to the model in order to determine whether the relationship between Lyme disease incidence and June temperatures (t–2 years) was quadratic. The *F*-test for a change in the coefficient of determination was utilized in order to determine whether improved prediction in the variance of Lyme disease (LD) incidence was realized as a result of the inclusion of the quadratic term (56). Diagnostic analysis revealed that the residuals of the aforementioned models did not conform to a Gaussian distribution; therefore, each model was bootstrapped with 1,000 resamples so as to improve the precision of estimates (57, 58). The regression equation for the final model is shown below (Eq. 1).

$$Y_{LD} = \alpha + \beta X_{Rural} + \beta X_{No\ HS} + \beta X_{Income} + \beta X_{Temp} + \beta X_{Precip} + \beta X_{Forest} + \beta X_{POP} + \beta X_{VET} + \beta X_{Temp}^2 + \varepsilon \quad (1)$$

Fourth, because a scatterplot for the relationship between Lyme disease incidence and temperatures exhibited a curvilinear relationship, further analysis regarding the aforementioned relationship was conducted. Specifically, June 2013 temperatures were recoded into three categories:

(a) low, $40.000^{o}F - 59.999^{o}F$, (b) medium, $60.000^{o}F - 69.999^{0}F$, and (c) high, $70.000^{o}F - 89.999^{o}F$. Then, a one-way ANOVA (59) was carried out with post-hoc comparisons in accordance with the Tukey Honestly Significant Difference (HSD) procedure (60) in order to determine the temperature range most hospitable to the development of Lyme disease. Each pairwise comparison was conducted with a bootstrapping procedure (1,000 resamples) in order to improve the accuracy of inference regarding mean differences in the population (61).

Results

As indicated in Figure 1, Lyme disease was particularly prevalent and concentrated in the upper midwestern and northeastern regions of the U.S. in 2015. The average incidence rate for counties in the northeastern region of the U.S. was 115.602 per 100,000, which was followed by an average incidence rate in the Midwest region of 12.596 per 100,000 (Table 1). Middlesex county, Massachusetts had the greatest number of reported Lyme disease cases in 2015 with 704 (incidence rate of 53.548 per 100,000). Significant variation in social and environmental conditions was evident within and between the four regions of the U.S. In the northeastern region, where Lyme disease was most prevalent, forested area was relatively abundant, June temperatures in 2013 were in the mid 60's, precipitation in 2013 was higher than other regions of the U.S., household income was higher than other regions of the U.S., and the percent of residents with less than a high school education was relatively low. Veteran population composition was highest in the western region, followed by the Midwestern, northeastern, and southern regions.
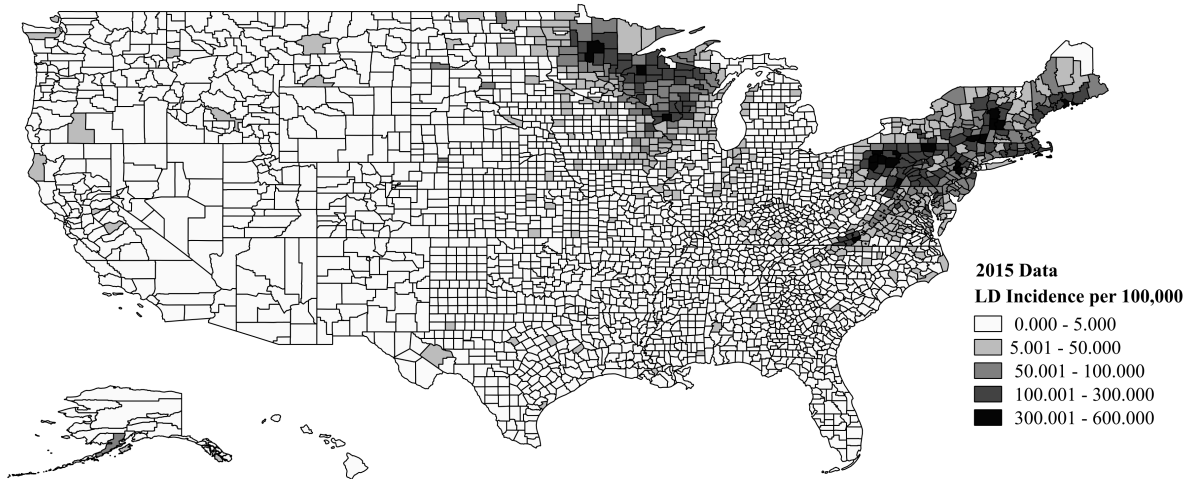

Figure 1. Geographic distribution of county-level Lyme disease incidence rates in the U.S. in 2015.

Table 1. –Regional differences in Lyme disease, social circumstances, environmental characteristics, and veteran population composition

	Northeast Region (Valid n = 191)		Midwest Region (Valid n = 789)		South Region (Valid n = 995)		West Region (Valid n = 370)	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
LD Incidence[a]	115.602	114.398	12.596	38.896	4.731	20.666	0.597	3.748
Rural[b]	3.341	2.310	5.579	2.668	4.708	2.652	5.435	2.686
No HS[c]	10.778	3.470	11.032	4.417	18.558	6.313	12.083	6.169
Household Income[d]	57.155	13.943	50.688	9.370	44.688	12.399	51.963	13.310

June Temperature[e]	66.525	3.3176	69.212	4.404	77.332	4.455	63.157	10.755
June Precipitation[f]	8.625	2.429	4.054	2.272	4.525	2.424	0.956	1.045
Forested Area[g]	55.705	21.564	21.468	23.290	52.608	23.582	36.920	26.415
Percent Veteran	9.418	2.895	9.860	2.455	9.400	3.069	10.445	4.197
Total County Population[h]	212.785	327.102	53.271	181.143	70.708	198.631	143.437	537.647

[a] Rate per 100,000

[b] Measured on a scale from 1 to 9, where a score of 1 was indicative of an extreme urban environment and a score of 9 was indicative of an extreme rural environment

[c] Measured as the percent of residents without a high school education

[d] Measured as the median household income (USD x 1000)

[e] Average temperature in June 2013

[f] Total precipitation in June 2013

[g] Percent of forested land

[h] Population averages are reported in thousands

Results of the two-block, hierarchical regression analysis are shown in Table 2. Model 1, where Lyme disease incidence rates were regressed on rurality, educational attainment, household income, temperature, precipitation, forestation, the total county population, and the proportion of the county population that had served in the U.S. Armed Forces, demonstrated overall statistical significance, $F(8, 2337) = 147.192$, $p < 0.001$, $R^2 = 0.335$. Results indicated that Lyme disease was more prevalent in rural counties with higher educational attainment and higher household incomes, relatively high June 2013 precipitation levels, and widespread forestation. Given that the 2013 temperature variable was tested for a quadratic relationship with Lyme disease incidence in Model 2, the interpretation of the June temperature independent variable was suspended until the results of Model 2 were generated.

Model 2, where Lyme disease incidence rates were regressed on each of the independent variables included in Model 1 as well as June 2013 temperatures squared, was statistically significant, $F(9, 2336) = 132.157$, p < 0.001, $R^2 = 0.337$. Results of the F-test for a change in the coefficient of determination in Model 2 was also statistically significant, $F(1, 2336) = 8.234$, $p = 0.004$, indicating that the quadratic temperature term increased the accuracy of the model. Therefore, the following interpretation of the relationship between Lyme disease incidence rates and temperatures (t–2) is tenable: Lyme disease cases are less prevalent in counties with extreme June temperatures, neither extremely cold nor extremely warm. Furthermore, in Model 2, results showed that Lyme disease incidence rates were higher in counties with greater veteran populations.

Table 2. –Social and environmental predictors of Lyme disease in 2015							
	Model 1[a]				Model 2[a]		
	b		SE	95% CI[b]	B		SE	95% CI[b]
Constant	2.019	*	0.024	1.967, 2.062	1.660	*	0.097	1.471, 2.062
Rural	0.002	*	0.001	0.001, 0.004	0.002	*	0.001	0.001, 0.004
No HS	-0.001	*	< 0.001	-0.002, -0.001	-0.001	*	< 0.001	-0.002, > -0.001
Household Income	0.001	*	< 0.001	< 0.001, 0.002	0.001	*	< 0.001	< 0.001, 0.002
June Temperature	-0.002	*	< 0.001	-0.003, -0.001	0.008	*	0.003	0.003, 0.014
June Precipitation	0.018	*	0.001	0.016, 0.020	0.017	*	0.001	0.015, 0.019
Forested Area	0.063	*	0.008	0.047, 0.077	0.067	*	0.008	0.052, 0.083
County Population	-0.001		< 0.001	-0.002, 0.001	0.001		< 0.001	-0.001, 0.002

| Percent Veteran | 0.135 | 0.070 | -0.002, 0.279 | 0.160 | * | 0.069 | 0.029, 0.301 |
| June Temperature Squared | | | | -0.001 | * | < 0.001 | -0.002, > -0.001 |

[a] Regression model estimates were obtained via bootstrapping with 1,000 resamples
[b] Confidence intervals were bias corrected
* Statistically significant based on a 95% BCa CI

In order to further explore the relationship between June temperatures (t–2) and Lyme disease incidence rates, a one-way ANOVA was calculated with June temperatures recoded into three categories: low (L), medium (M), and high (H). Results of the omnibus one-way ANOVA showed that group differences were evident, $F(2, 2547) = 199.252$, $p < 0.001$. Post-hoc tests calculated according to the Tukey HSD procedure were carried out in order to determine pairwise differences. The following results were obtained: (a) L vs. M, mean difference = -42.335, bias corrected (BCa) bootstrapped 95% confidence interval (CI) -48.548, -36.600; (b) M vs. H, mean difference = 40.210, BCa bootstrapped 95% CI = 34.414, 46.415; (c) L vs. H, mean difference = -2.125, BCa bootstrapped 95% CI = -9.665, 5.414. The results of the previously described tests indicated that Lyme disease incidence rates in 2015 were highest in counties with June 2013 temperatures between 60.000^oF and 69.999^oF. In summary, the analyses in the present paper indicated that Lyme disease in 2015 was most prevalent in rural counties, with relatively high socioeconomic status, abundant forestation, wet conditions (t–2), and mid-range temperatures (t–2).

Discussion

When county level data were analyzed in this current study, the highest number of cases occurred in the Northeast. This finding was expected since Lyme disease is hyper-endemic in this region. One reason for the higher number of cases of *Lyme borreliosis* in this area is the discontinuity of forests, which has resulted from local human population growth. When large forests become fragmented into smaller segments, the number of small vertebrates, such as the white-footed mouse (the primary reservoir for *Borrellia* species), increases; therefore, more hosts are available for larval tick feeding. As a result, there is a greater chance that these ticks will become carriers of *B. burdorferii* (62). For military personnel stationed or retired in this location, the risk of exposure to infected ticks is high since routine training drills, other occupational duties, or leisure and recreation often occur in forested areas or short grass prairies (32,34).

In this study, Lyme disease incidence rates were higher in counties with greater military veteran population compositions. Given the usual outdoor pastimes and hobbies of typical retired veterans and their families, such as hunting, fishing, camping, or exercising outdoors, increased exposure to TBDs–such as Lyme disease–comes as no surprise. The relatively recent increase in TBD case numbers among military personnel illustrates this observation (32). This finding also coincides with other conjectures in the literature (35). Lyme disease cases being less prevalent in counties with extreme June temperatures could coincide with veterans and others enjoying the outdoors more when temperatures are 60-70 degrees Fahrenheit, further exposing themselves to the tick vector.

A strength of this study stems from the fact that historically validated predictors of Lyme disease were considered (i.e., weather factors and social factors) as controls, allowing the researchers to examine the unique effect of veteran population composition on Lyme disease incidence rates in the U.S. While some studies have evaluated Lyme disease in European military-connected

populations, little empirical evidence for risk of Lyme disease among American military-connected populations exists (31, 34, 35). Future research is needed in order to validate the findings of this study and other exploratory studies; however, this study provides a first step–beyond anecdotal evidence–towards establishing increased risk for Lyme disease among American military-connected persons, especially veterans.

Limitations

Some limitations accompanied the collection and analysis of data in the present study. First, this study was cross-sectional in nature; therefore, causal relationships were not examined. Second, the Lyme disease case data were for the general population–not military personnel specifically. The primary goal of the study, then, was to determine whether military veterans live in areas where Lyme disease is hyper-endemic. While the results of our study showed that a positive association existed in 2015 between veteran population composition and Lyme disease incidence rates, further research is needed in order to validate this place-based risk.

Conclusion

Military veterans who have had previous exposure in Lyme-endemic areas are at increased risk of developing various manifestations of Lyme disease (31). In this current study, Lyme disease incidence rates were higher in counties with greater veteran populations in the U.S. in 2015, even after adjusting for the historically validated predictors of Lyme disease in the literature. While it has been speculated in the past that a possible relationship existed (due to occupational, rehabilitation, or perhaps outdoor leisure activities of veterans), this study has statistically reinforced the notion that veterans are at increased risk for Lyme disease owing to their choice of geographic residence. Not only does this research further expose the growing national health concern of vector borne diseases, particularly those spread by various species of ticks, but it also increases awareness that our nation's veterans are vulnerable to a myriad of negative health consequences.

Expanding the focus of the effects of Lyme disease is imperative for clinical and scientific professionals. We must increase our understanding of just how far-reaching and impacting its consequences are. Lyme disease by itself has been associated with numerous varied health sequelae, including but not limited to, arthritis, specific and non-specific neurological manifestations in both the central and peripheral nervous system, acute and chronic skin changes, and even cardiac manifestations (63, 64). Suicidal ideation has even been reported as part of the constellation of possible eventual symptoms, an outcome that is compounded by the high incidence of PTSD in the military veteran population (65). Since its initial discovery in Lyme, Connecticut in 1976, medical and scientific research has continued to pursue numerous aspects of the disease including microbiology, association with the environment, and clinical manifestations. While our overall understanding has increased tremendously over the last several decades, areas for future research and exploration continue to remain open. One such area includes Lyme disease's incidence, clinical manifestations, and overall impact on specific vulnerable populations, such as U.S. military veterans and their families.

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