Vector-Borne Diseases of Public Health Importance for Personnel on Military Installations in the United States

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Vector-borne diseases (VBDs) are among the leading causes of morbidity and mortality worldwide. The history of US military medicine dates from the formation of the Continental Army in the 1770s.[1] From the inception of our nation, the US military has combated infectious diseases. Today, scientific research programs at Walter Reed Army Institute of Research, the Uniformed Services University of the Health Sciences, and other institutions are major components in this effort. Additionally, the armed forces have worked to prevent the spread of disease through active public health measures such as the establishment of vector control programs at military bases, and international scientific collaborations aimed at increasing our prevention proficiencies.[2] While VBDs are of considerable concern for internationally deployed active military and civilian personnel, the concern for acquisition of VBDs in US territories and states has also been a reality for centuries. Endemic, emerging, and newly introduced VBDs have spread across the United States and its territories, creating foci of disease transmission. Military personnel are particularly susceptible to VBDs due to their increased contact with vectors during outdoor training exercises, military response missions, and occupational-specific exposures.

US Military Entomology Infrastructure

Vector control and pest management across the Department of Defense (DoD) involves a multitude of organizations both internal and external to the DoD. Born from a need to address the countless casualties and mission cost attributed to VBDs during World War II, the Army War Department established the Army Committee for Insect and Rodent Control (ACIRC) in 1944. In 1956, *DoD Instruction 5154.12* established the Armed Forces Pest Control Board replacing the ACIRC. By 1979, the title was amended to its current form, Armed Forces Pest Management Board (AFPMB), to better reflect the goal of balancing vector and pest control with environmental protection. The AFPMB is composed of pest management and medical entomologists from the Air Force, Army, Navy, and the Defense Logistics Agency (DLA). It has a strategic mandate from the Office of the Assistant Secretary of Defense for Acquisition, Technology and Logistics to recommend policy, provide guidance, and coordinate the exchange of information on all matters related to pest management throughout the DoD. Service entities including the Army Public Health Center, Navy Entomology Center of Excellence, Walter Reed Army Institute of Research, Walter Reed Biosystematics Unit, and Armed Forces Health Surveillance Center assist in the coordination and implementation of DoD and/or service-specific pest management policies and guidance. The AFPMB is the lead pest management agency for the DoD, coordinating with other US government (USG) agencies, non-USG organizations, and other foreign organizations as well, including the Environmental Protection Agency, US Department of Agriculture, US Centers for Disease Control and Prevention (CDC), North Atlantic Treaty Organization, and the World Health Organization.

Vector control programs employed by the US armed forces date from the late 1800s, when mosquitoes were first identified as vectors for human disease pathogens.[3] Vector management programs evolved into their modern form during the 1970s with the development of integrated mosquito control programs focused on a multifaceted approach designed to manage the target pest with integrated measures to mitigate risk of vector disease transmission while balancing risk of pesticide exposure and environmental risk. The introduction of West Nile virus into naïve US mosquito populations[4] and the recent chikungunya-Zika Latin American epidemics have created a shift in the paradigm of vector control programs.[5] Programs have now begun to balance the concern for environmental effects of pesticide use on a large scale with the threat of invasive mosquito species and their respective capacities to introduce emerging VBDs within our borders. Currently, several endemic VBDs continue to threaten our military and civilian populations residing

within US borders. Additionally, emerging arboviral diseases in Latin America threaten introduction into our resident mosquito populations,[6,7] and new pathogens are being identified on a regular basis through surveillance and innovative pathogen detection research investigations.[8-10] In this article, we present an overview of vector-borne diseases acquired by military personnel during field exercises and/or training evolutions within US borders and end with diseases of future concern and conclusions to reduce disease transmission in this population.

Mosquito-borne Diseases

West Nile Virus

West Nile virus (WNV) is transmitted by a variety of mosquito species found in the United States, primarily *Culex pipiens* Linneaeus in the north, *Cx. quinquefasciatus* Say in the south, and *Cx. tarsalis* Coquillett in the western states. Over 2,000 cases of WNV occur annually in the United States[11] with cyclic peak annual outbreaks.[12] Although many infected humans will not show signs of disease, 20% develop febrile illness, and 1% develop neuroinvasive disease (acute flaccid paralysis, meningitis, encephalitis or meningoencephalitis).[13] Neuroinvasive disease is a particularly concerning clinical manifestation, as these patients have the highest risk of long-term morbidity and death.[11] Diagnosis is made by detection of WNV viremia, or antibodies in the serum or cerebrospinal fluid. Acute disease diagnosis is complicated by the short duration of viremia antecedent to symptom onset and the sustained presence of IgM infection several months to years post-onset.[14] Evidence for persistent infection and/or sequelae exists, with patients continuing to report morbidity up to 11 years post-infection.[15,16] The economic burden from WNV infection is considerable with each individual case of acute neuroinvasive disease resulting in up to $51,240 in healthcare costs[17] and up to $400,000 in long-term loss of productivity wages.[18] Currently, there are no Food and Drug Administration approved treatments or vaccines for WNV infection; however, vaccine clinical trials are undergoing.[19] Surveillance has identified WNV activity at over 44 DoD sites,[20] resulting in nationwide vector control efforts.[21] The Armed Forces Health Surveillance Center reported 323 confirmed cases of WNV illnesses among Army, Navy, Marine Corps, Air Force, and Coast Guard personnel from 2006-2015.[22] An additional 245 cases were reported during that time, but the military branch of the patients was unknown and those cases could include contractors, civilians, and foreign nationals.

Dengue Virus

Dengue virus (DENV) is transmitted by *Aedes aegypti* (L.) and *Ae. albopictus* Skuse mosquitos found throughout the southern United States, with the *Ae. albopictus* vector geographic range reaching north to Minnesota and Maine.[23] Globally, 4 serotypes (DENV 1-4) have been well characterized, with a fifth serotype having recently been proposed in Malaysia.[24] Infection with one serotype does not provide cross-protection from other serotypes, and multiple serotype exposures increases one's odds of developing severe clinical outcomes, such as dengue hemorrhagic fever and shock syndrome. Symptoms of DENV fever are nonspecific (fever, headache, joint, muscle, and bone pain), with symptom onset typically occurring 4-7 days after vector transmission and lasting 3-10 days after symptom onset. As the fever is residing, warning signs for serious clinical manifestations can present, including capillary leakage, marked temperature change, thrombocytopenia, change in mental status, rapid weak pulse, and hemorrhagic manifestations that can rapidly progress to circulatory system failure and shock.[25] Although the majority of dengue cases in the United States are travel-related, autochthonous transmission has occurred along the Texas/Mexico border, as well as in Florida and Hawaii.[26-30] Diagnosis is determined by laboratory confirmation of viremia or antibodies. There is no specific treatment for DENV infection; however, fluid replacement treatment and pain relievers may improve outcomes among critically ill patients. Vaccine trials are underway[31]; but controlling mosquito populations in the interim is the best method for disease prevention. Between 2006 and 2015, approximately 700 cases of dengue fever were reported in military personnel.[32] Due to the rarity of the locally-acquired disease in most of the United States, one would assume most individuals acquired the infection during deployment to endemic regions. While only focal outbreaks of autochthonous transmission have occurred in the United States, military installations in regions where *Ae. albopictus* and *Ae. aegypti* exist should monitor for the potential of autochthonous infections.[26-30]

Other Endemic Arboviral Infections of Concern

St. Louis encephalitis (SLE) is a *Culex* sp. transmitted flavivirus infection of notable historical importance,[33] as this disease served as justification for the foundation of new vector control authorities across the country. While SLE is less prevalent due to the recent establishment of WNV, cases are still reported annually and it is a regular contributor to neuroinvasive disease nationally.[34] Alphaviruses are another group of positive-sense RNA viruses transmitted through the bite of an infected mosquito and are a member of the Togaviridae family.[35] They typically result in encephalitis or arthralgia. Western equine encephalitis (WEE), Eastern equine encephalitis (EEE), and Venezuelan equine encephalitis (VEE) viruses are encephalitic alphaviruses, while chikungunya

is an arthralgic alphavirus. *Aedes*, *Culex*, *Psorohpora*, and C*uliseta* are all known to transmit alphavirus infections. For the encephalitic alphaviruses, most infections are asymptomatic, but febrile illness can onset 2-10 days after infection and progress to encephalitis in approximately 5% of people.[35] Most EEE cases are reported in Florida, Georgia, Massachusetts, and New Jersey, but transmission is most common around the freshwater hardwood swamps in Atlantic states, Gulf Coast states, and the Great Lakes regions.[36] Most WEE cases occur in Texas, Colorado, Oklahoma, and New Mexico.[35] Most VEE cases occur in Central and South America, but spillover cases have occurred in Texas.[37] Complications of encephalitis can occur with lifetime care costs exceeding $4.6 million per patient.[35] According to the Armed Forces Health Surveillance Center, at least 107 cases of mosquito-borne viral encephalitedes (contributable to either WEE, EEE, or other less common arboviruses) were reported between 2005 and 2014, with cases originating annually from the Marines, Army, Air Force, and Navy,[38] further demonstrating their contributory role in serviceman illness.

Tick-borne diseases

Lyme disease

Lyme disease, also referred to as Lyme borreliosis, is caused by different genospecies of the bacterium *Borrelia burgdorferi* Johnson sensu lato.[39] This vector-borne infection is endemic to the majority of the northern hemisphere with active transmission ongoing in Europe, Asia, and the United States.[40] Multiple species of the *Ixodes* ticks are capable of propagating sylvatic transmission of this pathogen in the United States, but only two are implicated in human transmission: the black legged tick (also called the deer tick) (*Ixodes scapularis* Say), and the western black-legged tick (*I. pacificus* Cooley and Kohls).[41] Initial symptoms after exposure through the bite of an infected tick often include the development of a rash around the sight of inoculation referred to as erythema migrans, colloquially called a "bulls-eye" rash. In addition, many patients concurrently experience fatigue, headache, arthralgia, malaise, and myalgia. Rarely the disease can disseminate after initial infection and cause symptoms including carditis, neurologic complications, and arthritis.[42] Oral antibiotics such as doxycycline, amoxicillin, or cefuroxime axetil are commonly prescribed for treatment of Lyme disease.[43] Patients treated rapidly after onset of infection often recover completely. However, delayed diagnosis and treatment may lead to a higher likelihood of developing severe disease. Lyme disease is among the most commonly reported VBDs in the United States, with an annual incidence of around 300,000 cases.[44] It has long been proposed that individuals with occupations or hobbies that require extended time spent outdoors, such as military training exercises, in endemic areas are at elevated risk for contracting Lyme disease.[45]

Historically, the armed forces have struggled with Lyme disease infection in military trainees, active duty Soldiers, military dependents, and civilian contractors working on military bases and installations. Reports of infection date back to 2 years after the pathogen was first isolated. A naval base in New Jersey reported an incidence rate of 1,063 cases per 100,000 personnel between 1981 and 1982. Identification was based on clinical diagnosis as serologic testing was not yet available, introducing the possibility that this number underrepresents the true burden of disease due to misdiagnosis.[46] Further highlighting this issue, 2 case reports identified military personnel that were not identified until disseminated Lyme disease had developed, and presented with rare symptoms including carditis and neurologic complications.[47,48] The late 1990s was a period of low incidence. It was estimated that only 6 seroconversions occurred during military duty per 100,000 persons.[49,50] Reports of Lyme disease among all branches of the military steadily increased in the early 2000s.[51,52]

In 2006, an entire 110-person unit was preemptively treated for Lyme disease after a training exercise at Fort Dix, New Jersey. Between one and 2 weeks after the exercise, at least 5 personnel were diagnosed with erythema migrans. Watchful waiting was judged to be too high of a risk for this unit as they were preparing to deploy to an austere location in less than 2 weeks. Given the risk of cardiac and neurologic complications presenting in such circumstances, the entire unit received a 2-week course of doxycycline for early Lyme.[53] In 2011, a spike in cases was reported, at its peak 16 per 100,000 active duty personnel and 25 per 100,000 reservists were screened positive for *B. burgdorferi* exposure.[54] Incidence of military exposure appear to correlate with base location, with the highest incidence in the northeastern United States.[55] Reports indicate that a correlation exists between pathogen quantity in ticks removed from military personnel and human prevalence of disease at a given base, indicating that this may serve as an effective surveillance tool for detection of high risk areas and prevention of disease outbreaks.[56] This method might be particularly useful to distinguish between transmission sources for returning serviceman from European installations where transmission is also possible.[57]

Ehrlichiosis

First reported in the United States in 1986, human ehrlichiosis is caused by infection with either *Ehrlichia chaffeensis* Dumler (human monocyte ehrlichiosis) or *E.*

ewingii Dumler.[58] This zoonotic pathogen is an obligate intracellular bacterium that often infects monocytes, forming distinct *Ehrlichia* colonies. Cases are most often reported in the southcentral and eastern regions of the United States. This corresponds to the geographic region of naturally occurring lonestar ticks (*Amblyomma americanum* Linnaeus), the primary vector for both *Ehrlichia* species.[59] Within one to 2 weeks of exposure, patients typically develop general febrile illness and a subset present with a wide range of rash (maculopapular to petechial). If not identified and treated promptly, ehrlichiosis can cause more severe symptoms including difficulty breathing and abnormal bleeding, with a 1.8% case fatality.[60] The primary treatment is oral doxycycline for both adult and pediatric cases.[61] It is recommended that the antibiotic be prescribed even in suspected cases due to the severe and even fatal nature of this infection.

Among the first reports characterizing the causative agent of human ehrlichiosis includes a case-report of an Army reservist with tick exposure during a field exercise at Fort Chaffee, Arkansas.[62] Following this discovery, a prospective serologic investigation was launched to determine seroprevalence of *Ehrlichia* at Fort Chaffee and surrounding bases. Seroconversion was detected in 1.3% of the Soldiers with available pre-exposure samples (n=1,194) with 33.3% of seropositive personnel reporting a previous clinical history consistent with ehrlichiosis. Additionally, seropositive military personnel were significantly more likely to report history of tick attachment (RR=3.56, $P<.2$), indicating that active tick-borne transmission of *Ehrlichia* was ongoing during field exercises at bases within Arkansas.[63] A second outbreak was detected at a New Jersey base, where 12% of personnel screened seropositive (n=74) with all 9 cases recalling tick exposure during field exercises in knee-high grass.[64] Additional sporadic human case reports and *Ehrlichia* pathogen positive ticks collected from military personnel indicate this is an ongoing threat to military personnel performing field exercises in the eastern and southcentral portions of the United States.[52,65,66]

Rocky Mountain Spotted Fever

Rocky Mountain spotted fever (RMSF, infectious agent *Rickettsia rickettsia* Ricketts) is endemic to the United States,[67] and is sometimes referred to as spotted fever group rickettsiosis when including other less commonly transmitted rickettsial pathogens (*R. parkeri* Lackman and *Rickettsia* spp. 364D). Transmission has been noted throughout the contiguous 48 states, with a burden of disease occurring in the southcentral states. The primary vector for RMSF is the American dog tick (*Dermacentor variablilis* (Say)).[68] Symptoms of disease present 2 to 14 days after exposure and typically begin with a nonspecific fever and headache. Infection is often misdiagnosed at onset, due to the initial nonspecific nature of disease. Typically, it is not until the characteristic rash associated with infection forms 2 to 5 days following onset of symptoms, that the disease is positively identified.[68] Some individuals will have a more severe infection that can lead to vasculitis, and abnormal bleeding in the brain and/or vital organs. Those who experience severe disease symptoms often suffer from sequelae as a result of infection. Diagnosis of RMSF can be difficult as no serologic test are available to detect acute infection, and is largely determined by clinical symptoms and epidemiologic exposures. Once a case is identified, prompt doxycycline administration is critical to limit disease severity.[67] Given the frequency of movements of military trainees from one geographic location to another, this often presents well outside its usual geographic range. A thorough travel history is an essential component for the patient exam of any military personnel presenting with an acute febrile illness in order to consider geographically limited but life-threatening infections like RMSF.

Rocky Mountain spotted fever has affected military personnel and working dogs stationed across the United States since 1982. A serosurvey of dogs (N=467) housed at 4 different military bases across the country found 32% were seropositive, with a range of 4.3% to 63.4% depending on region. Additionally, a higher rate of RMSF exposure was reported (87%) in the working/sporting dogs breeds screened.[69] Prevalence in canine populations were seemingly in parallel with human seroprevalence in the same geographic region during this time period, suggesting that dogs may provide an efficient sentinel for infection.[69,70] At the same Arkansas base where Yevich and colleagues[63] reported *Ehrlichia* infections, a serosurveillance study detected 2.5% of military personnel (n=1,194) had seroconverted for RMSF. While less than a quarter of individuals that developed antibodies for RMSF had clinical symptoms (8/30), disease status was strongly associated with history of tick bite (RR=4.3 $P<.001$).[63] Reports continue to emerge linking cases of RMSF to field exercises in the United States,[71] detecting seroconversion in military troops,[52,72] and identification of pathogen from ticks implicated in human bites.[65]

Tick-borne Relapsing Fever

Tick-borne relapsing fever (TBRF) occurs when *Borrelia* spirochetes (predominantly *B. hermsii* Steinhaus and *B. turicatae* Steinhaus) are transmitted to humans by *Ornithodoros* ticks. These soft-shelled Argasidae ticks differ from hard Ixodidae ticks in several key characteristics: they have multiple nymphal stages; they feed

rapidly, typically between 15 and 90 minutes; as adults, they can feed and reproduce repeatedly, are capable of surviving for several years between blood meals[73]; and the spirochetes may colonize their salivary glands, rather than the midgut, allowing for rapid deposition after host attachment.[74] An infected human usually displays an influenza-like illness, often with some degree of altered mental status, after a mean incubation period of 7 days (range: 4-18 days). Although severe disease is atypical, acute respiratory distress syndrome and other serious sequelae have been reported. More commonly, the initial illness resolves in 3 days (range: 0.5-17 days), followed by an afebrile interval of approximately one week and then a relapse of fever. Since borreliae can vary their surface protein antigens repetitively, multiple relapses are possible. Febrile episodes typically become shorter and less severe over time. The mortality rate is well below 5%, with some fatalities attributed to a Jarisch-Herxheimer reaction after antibiotic initiation.[73] Diagnosis of TBRF may be confirmed by visualization of spirochetes on thick or thin smears using Giemsa or Wright stains during febrile episodes, although serologic and molecular techniques are becoming increasingly available.[75] The mainstay therapy for infected adults is a 7-10 day course of oral doxycycline (100 mg every 12 hours); other oral and parenteral antibiotics are also effective.[73]

Isolated cases or small clusters of TBRF are possible during military field training exercises in endemic regions of the country, most notably Florida, Texas, and the Pacific West. Sleeping on floors in close proximity to the natural habitat of *Ornithodoros* ticks, such as in limestone caves or rodent-infested cabins, is particularly risky.[76] In the summer of 2015, an Army Soldier contracted TBRF during a 30-day field exercise in northwestern Texas, likely while sleeping in an abandoned barn-like structure. He was hospitalized with fever and marked thrombocytopenia but recovered rapidly after initiation of doxycycline. Postexposure prophylaxis was provided to 10 soldiers in his detachment, none of whom became ill.[77] This case provided the first human isolate of *B. turicatae*[78] and should remind military public health personnel to emphasize tick control and personal protective measures during field exercises in TBRF endemic areas. When these measures cannot be followed, or when the risk remains high despite their implementation, postexposure prophylaxis with oral doxycycline should be considered.[79]

Other Tick-borne Diseases of Concern

Several additional endemic tick-borne diseases exist in the United States. Anaplasmosis (*Anaplasma phagocytophilum* Dumler rickettsial infection) is transmitted to humans by *I. scapularis* ticks and results in approximately 2,600 incident cases annually, primarily in northeastern and midwestern states.[80] A recent seroprevalence study of the DoD Serum Repository identified a 0.11%-2.6% *A. phagocytophilium* positive rate among a geographically diverse sample of servicemen, identifying this pathogen as an important cause of illness in military populations.[72] Colorado tick fever is another cause of undifferentiated febrile illness, occurring primarily at altitudes of 4,000 ft to 10,000 ft and transmitted by *D. andersoni* Stiles.[81,82] It can result in serious complications, including pericarditis, meningitis, and/or encephalitis. Tularemia infection (caused by *Francisella tularensis* Dorofeev) is a potentially life threatening illness that can be transmitted by *Dermacentor* sp., *Amblyomma* sp., and *Ixodes* sp. ticks, among other nonvector transmission sources. Tularemia has been reported from all contiguous states, but is most common in southcentral states and the Pacific Northwest.[83] Powassan encephalitis is a rare but serious viral tick-borne disease common in the northeastern United States, primarily transmitted by *I. cookei* Packard vector, although other *Ixodes* sp. and *D. andersoni* can be vectors.[81,82]

Other vector-borne diseases

Chagas Disease

An estimated 6 to 8 million people are infected with Chagas disease.[84] The disease results from infection with the protozoan parasite *Trypanosoma cruzi* Chagas is transmitted to humans through one of several routes: vector-borne, congenital, blood-borne, oral, and organ transmission. It is most commonly acquired via vectorborne transmission.[84] More than 130 triatomine species in the Americas can be infected by and transmit *T. cruzi*.[85] In the United States, the greatest diversity is found in southwestern states; *Triatoma sanguisuga* LeConte is the most widely distributed, yet *T. gerstaeckeri* Gerstaecker is the most commonly collected.[85] Autochthonous infection potential increases as triatomine species adapt to human dwellings, and as human living environments and military field activities expand into areas of sylvatic disease.[86]

Infection occurs when a *T. cruzi* positive triatomine feeds and excreta contaminates the bite wound or mucosal tissue, entering the bloodstream. After an incubation period of 1 to 2 weeks, an acute phase of 8 to 12 weeks follows. During the acute phase, patients may be asymptomatic, have mild symptoms, or local inflammation at the bite site; however, less than 1% will have severe acute disease that manifests as acute myocarditis and/or pericardial effusion.[87] Chronic infection occurs in 3 forms: indeterminate, cardiac, or gastrointestinal disease. Most infections remain in an indeterminate

phase for life and have positive anti-*T. cruzi* serology, but no clinical signs or symptoms.[86] Approximately 20% to 30% of indeterminate cases progress to cardiac and/or gastrointestinal disease years or decades later. Cardiac disease is detected by abnormal electrocardiogram, and symptomatic disease may present as aneurysm, thrombus formation, or congestive heart failure.[87] Less commonly, progression leads to gastrointestinal disease affecting the esophagus and/or colon, leading to motility disorders, megaesophagus, or megacolon.[88] Treatment with nifurtimox or benznidazole may be indicated for acute and indeterminate chronic disease to decrease symptoms and clinical course, but must be obtained from the CDC and administered under an investigational protocol.[88] Two case reports of servicemen with military and childhood exposures have been published, highlighting the potential for disease transmission among military personnel in the United States.[89,90]

Other Endemic Vector-borne Diseases of Concern

Leishmaniasis is a parasitic infection (20+ *Leishmania* sp.) transmitted by sand fly vectors (30+ *Phlebotomus* sp.), and can manifest clinically as either cutaneous or visceral forms of disease. Two genetic lineages exist that correspond to either Old World infections (Asia, Middle East, and Africa) or New World infections (Western Hemisphere). While vector-borne transmission is most common, anthroponotic transmission has occurred,[91] heightening concern of this disease among our armed forces personnel living in close quarters. While military cases have not been reported, autochthonous leishmaniasis human cases have been reported from Oklahoma and Texas,[92] implicating these states as possible transmission risk areas for military operations and training. Trench fever (*Bartonella quintana* Schmincke infection) is transmitted by the human body louse (*Pediculus humanus humanus* Linnaeus), and manifests clinically as nonspecific febrile illness, bacillary angiomatosis, or endocarditis.[93] While trench fever was historically a major concern in World War I, it has yet to be reported among contemporary service personnel; however, high rates of infected body louse among American homeless populations[94] indicates a potential risk to military personnel in contact with these populations, ie, those serving in natural disaster response operations. Murine typhus is a typhus group rickettsiosis transmitted by rat fleas (*Xenopsylla cheopis* Rothschild) and cat fleas (*Ctenocephalides felis* Bouché), which can present as nonspecific febrile illness, conjunctivitis, and/or heptosplenomegaly. Murine typhus is a reemerging disease with geographic distribution in Hawaii,[95,96] Texas,[97] and California.[98]

Diseases of Future Concern

> *Should the disorder infect the Army, in the natural way, and rage with its usual virulence, we should have more to dread from it, than from the Sword of the Enemy.*
>
> Letter from General George Washington to the Continental Army Surgeon General, Dr William Shippen, February 6, 1777.[99]

Whether engaging in stateside-based training activities, traditional major combat operations, or humanitarian assistance missions, US armed forces military personnel have always had to grapple with ubiquitous vector-borne diseases which have rivaled bayonets, bullets, missiles, and mortars throughout history as the causes of morbidity, mortality, disability, and diminished operational effectiveness. While certain diseases have lost their military importance (yellow fever,[100] plague,[101] and epidemic typhus,[102,103]), others remain of concern (dengue fever,[102,104] leishmaniasis,[102,105-107] West Nile encephalitis,[108] and malaria[100,109]), and emerging diseases have recently occurred (Zika virus[110] and chikungunya fever[111]) that affect operational forces.

Leishmaniasis, characterized by the CDC as a "neglected tropical disease," persists as a pestilence of future concern. The facts that the incidence of cutaneous leishmaniasis among US military during operations in Iraq and Afghanistan was substantial,[112] and it is endemic in 88 countries[113] are reasons to keep this condition on military preventive medicine's radar. Notably, there has also been an upsurge of cutaneous leishmaniasis among Syrian refugees in traditionally nonendemic locations,[114] including Europe.[113,115] Furthermore, leishmaniasis has been identified in Texas and other areas of the southern United States,[116,117] complicating the ability to accurately identify origin of infection in returning military personnel.

Mayaro virus, of the genus *Alphavirus* in the family Togaviridae, is a close relative of chikungunya that produces an analogous debilitating arthralgic disease in South America. Mayaro could be endemic in regions across the continent but camouflaged by the unspecific symptoms it shares with other mosquito-borne viruses. First isolated from febrile forest workers in Trinidad in 1954,[118] the etiologic agent of Mayaro fever has been identified in French Guiana, Suriname, Venezuela, Peru, Bolivia, Brazil,[119] and Haiti.[120] The apparent primary vectors, *Haemagogus* mosquitoes, inhabit rural settings, a reason that may justify the relative paucity of cases and inhibited endemicity. Conversely, *Ae. aegypti* mosquitoes have been shown to be competent vectors of Mayaro virus,[121] signifying that an urban-dwelling arthropod could potentially be a vector of this virus on

a global scale. Because Mayaro virus symptoms can resemble those of both chikungunya and dengue, it may be underdiagnosed. While the Mayaro virus has not been linked with fatal human disease like dengue, primary infections are often more debilitating, with loss of productivity for weeks or even months due to severe arthralgia.

Military preventive medicine personnel should also be on guard for the Oropouche virus,[122] the Amazonian cousin of the Mayaro virus, which is spread through *Culex* sp. mosquitos and *Culicoides paraensis* Goeldi midges.[123] Both vectors are known to have a broader distribution[124] than the *Aedes* sp. mosquitoes that carry Zika virus.[125] Lastly, Ross River virus, which was previously thought to be indigenous to Australia and Papua New Guinea by sustaining itself in marsupials,[126] has been documented in Pacific Island travelers. The spread of these new geographic regions suggest the potential for further geographic expansion and global epidemic potential. Collectively, these arboviral pathogens not only infect people via enzootic spillover, but they use humans as amplification hosts and represent a tremendous risk for urbanization.[127] The latest epidemic activity of Zika and chikungunya should underscore the need to consider these diseases in febrile US service members returning from endemic areas and serve as a caution that presumably obscure viruses like Mayaro virus, Oropouche virus, and Ross River virus should not be underestimated as potentially emerging human pathogens.

Conclusion

Vector-borne diseases have been an important cause of morbidity and mortality since the inception of our nation. In line with the general population, military and civilian personnel acquire diseases while on stateside military installations, active missions, and training exercises. Military personnel with occupational duties resulting in extended time outdoors are potentially at an increased risk for VBD transmission. Development and implementation of integrated vector management plans can be useful tools to reduce vector exposure and transmission risk during disease outbreaks, in endemic disease areas, or in the event of emerging VBDs. As identified by the Armed Forces Health Surveillance Center, our military personnel routinely acquire a wide range of VBDs spread through mosquitoes, ticks, triatomines, and other arthropods. Our current review identified the VBDs of greatest public health concern to serviceman taking part in military missions and training in the United States. Vector surveillance, insecticide applications, and personal protection measures are warranted to prevent future infections.

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