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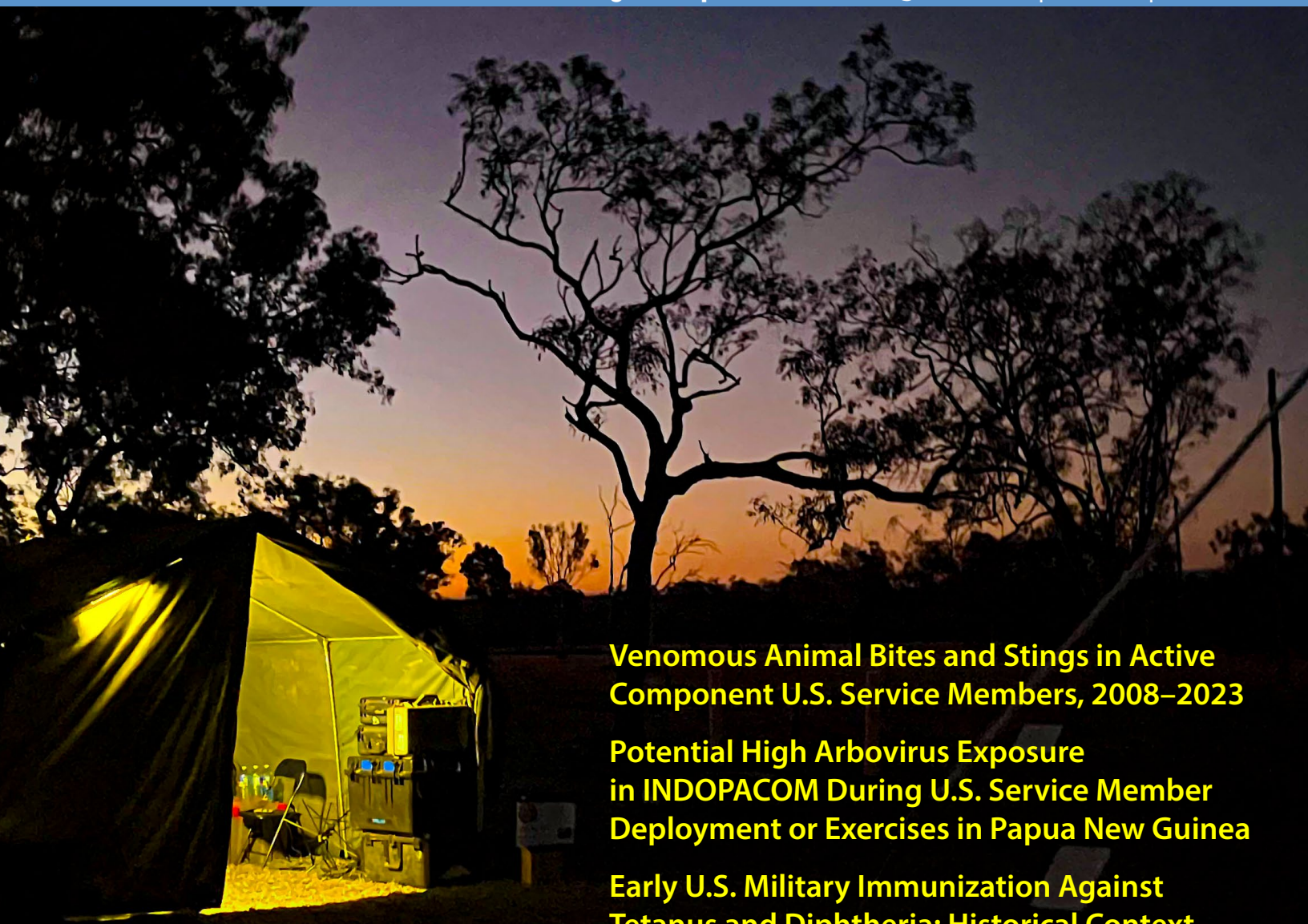

Venomous Animal Bites and Stings in Active Component U.S. Service Members, 2008–2023

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Medical Surveillance for Military Readiness

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Venomous Animal Bites and Stings in Active Component U.S. Service Members, 2008–2023

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This study characterizes all medically diagnosed bites and stings in active component service members (ACSMs) from snakes, venomous fish, other venomous marine animals, arthropods, and insects identified through an evaluation of medical data from the Defense Medical Surveillance System (DMSS). Incident trends were determined from 2008 through 2023, and incidence rates (IRs) and incidence rate ratios (IRRs) were calculated. In total, there were 42,552 venomous bite and sting medical encounters among 39,201 ACSMs, resulting in an IR of 19.3 cases per 10,000 person-years (p-yrs) during the surveillance period. Most cases occurred in men ages 20-34 years, non-Hispanic White individuals, Army service members, and junior enlisted ranks. IRs were elevated in female (25.0 per 10,000 p-yrs), youngest (<20 years, 24.5 per 10,000 p-yrs), and Coast Guard or U.S. Public Health Service (23.4 per 10,000 p-yrs) ACSMs. Arthropods were the primary source (75.0%) of stings and bites. IRR calculations suggest that women had a 37.0% higher risk than men. These study findings demonstrate the continuing susceptibility of ACSMs to venomous encounters and the importance of targeted prevention strategies, training, and comprehensive medical support to maintain force readiness.

What are the new findings?

Venomous bites and stings are a persistent health concern for active component service members. Arthropods are the most common culprit, but risks vary by sex, age, and military occupation. This report also reveals that younger service members and women are disproportionately affected.

What is the impact on readiness and force health protection?

Venomous bites and stings, while often non-fatal, represent a persistent health risk that affects U.S. military personnel readiness worldwide. Higher incidence among specific demographics (e.g., women and younger personnel) and occupations (e.g., veterinary) necessitates targeted force health protection measures. Further efforts to improve service member awareness, as well as preventive measures, may help reduce sequelae and mitigate impacts on military readiness.

Snake, marine animal (e.g., jellyfish, sea anemones), arthropod (e.g., scorpions, spiders), and insect (e.g., bees, wasps) envenomation can cause a range of adverse events—from mild irritation and limited necrosis of tissue to systemic reaction , renal, hepatic, cardiac or respiratory failure, failure, and death—with serious implications for the health and operational readiness of military personnel.[1]

Approximately 5.4 million people worldwide are bitten by snakes each year, with 1.8 to 2.7 million cases of envenoming, with most in Africa, Asia, and Latin America. Between 81,410 and 137,880 people die each year as a result of snake bite.[2] Marine envenomation is generally not medically significant and includes mild stings, bites, abrasions, and lacerations, with jellyfish stings the most frequent type worldwide, accounting for more than 150 million stings annually[4]; notable exceptions include lethal box jellyfish (*Chironex fleckeri*) or sea wasp stings, Irukandji jellyfish (*Carukia barnesi*) and blue bottle (*Physalia*) stings, and sea snake bites (*Hydrophiinae*) that occur most frequently in Australian and Pacific waters.[5] Arthropod envenomation accounts for a higher percentage human morbidity and mortality than snake or marine envenomation.[3] Medically significant scorpion sting encounters involve more than 1 million people annually, but with a low fatality rate.[6] Species that present common stinging threats include honeybees (*Apidae*), wasps, yellowjackets, hornets (*Vespidae*), and ants (*Formicidae*).[7] Allergic reactions to these hymenopteran insect stings are common, but in some cases, they can produce systemic allergic reactions that may lead to fatal anaphylaxis.

Previous studies specific to active component service members (ACSMs) have focused mainly on arthropod and snake envenomations. From 1990 through 1997, 728 ACSMs were hospitalized for arthropod or snake envenomations, with average hospitalization of 4.2 days.[8] A recent 5-year surveillance study of snakebite envenomation (SBE) among U.S. active and reserve component service members [9] revealed a total of 345 SBE diagnoses from 2016 through 2020. Most SBEs were among ACSMs, who were relatively young (ages 20-29 years) and in combat-specific or repair and engineering occupations.

The objective of this study was to characterize all medically diagnosed bites and stings in ACSMs from snakes, arthropods, venomous fish, and other venomous marine animals that were identified through an evaluation of medical data from

the Defense Medical Surveillance System (DMSS). This review also provides a summary of bites and stings service members sustained, by demographic and military characteristics including combatant command and location where bites and stings occurred and were treated.

Methods

This retrospective cohort study included all ACSMs of any branch of the U.S. Armed Forces during the surveillance period, from January 1, 2008 through December 31, 2023. Data were queried from the DMSS. Demographic information on age, sex, service, race and ethnicity, rank, and military occupation were included. International Classification of Diseases, 9th and 10th Revisions (ICD-9/ICD-10) diagnostic codes were used to define bites and stings from venomous animals (ICD-9: 989.5, E905.0; ICD-10: T63.0–T63.6, T63.8, T63.9) **(Table 1)**. From October 2015 through 2023, ICD-10 diagnostic codes, which are more exact than ICD-9 codes, were used to delineate bite and sting incident cases from specific categories of venomous animals.

ACSMs with either 1 inpatient or outpatient medical encounter for a venomous animal bite case-defining code in any diagnostic position were considered a case. The date of the first case medical encounter at military hospitals or clinics as well as private sector facilities was used as the incident date. Cases were counted once per year.

Person-time contributions for each service member were determined from January 1, 2008 through December 31, 2023. Person-time for each ACSM was calculated until the individual left active component service or were lost to follow-up, or the surveillance period ended, whichever occurred first. Since cases were counted once per year, person-time was not changed at the time of incident encounter.

Incident cases of venomous bites were determined according to key demographic variables. Incident cases from October 2015 through 2023 were further stratified by type of venomous animal, as ICD-10 codes provide more specificity than cases that were identified from ICD-9 codes in prior years. Crude incidence rates (IRs) were calculated as incident venomous bites per 10,000 person-years (p-yrs). The Poisson regression was used to calculate incidence rate ratios (IRRs) and 95.0% confidence intervals (CIs). The least at-risk sub-group of each demographic variable was selected as the reference group. All analyses were conducted using SAS Enterprise Guide (version 8.3).

Results

During the 16-year surveillance period, a total of 42,552 incident cases of venomous bites and stings were diagnosed among 39,201 ACSMs. Case-defining medical encounters with ICD-9 diagnostic codes identified 19,626 incident cases from 2008 through 2023, and ICD-10 diagnostic codes identified 22,926 incident cases from October 2015 through 2023.

Approximately 80.0% (n=33,887) of cases were among male service members. Nearly 70.0% (n=29,370) of cases occurred in those aged 20-34 years, 63.0% (n=26,879) occurred in non-Hispanic White individuals, 44.0% (n=18,930) were among junior enlisted ranks (E1–E4), and 40.0% (n=17,104) occurred in Army members **(Table 2)**. ACSMs in the repair / engineering and communications / intelligence occupational groups were most often affected by bites and stings, comprising nearly half of all bite and sting occurrences during the surveillance period **(Table 2)**.

Most bite and sting encounters reported from 2008 through 2023 occurred in the U.S., with 86.0% of bite and sting cases (n=36,629) in the U.S. Northern Command. The remainder of cases occurred in the U.S. Indo-Pacific Command (2,407 cases, 6%), U.S. European Command (n=1,334 cases, 3%), U.S. Southern Command (91 cases, >1), and U.S. Africa Command (7 cases, >1), while 5.0% (n=1,973) of cases were reported with missing or unknown locations (data not shown).

The preponderance of bite and sting encounters reported (n=22,926) from October 2015 through 2023 was from other arthropods (75.0%), with 10.0% (n=2,281) from spider bites, 5.0% (n=1,178) from venomous fish, 5.0% (n=1,215) from other venomous marine animals, 2.0% (n=512) from scorpion stings, 2.0% (n=415) from snake bites, and 1.0% (n=303) from unspecified venomous animals, with 100 encounters from "other" venomous animals **(Figure 1)**. From 2008 through September 2015, there was no stratification by animal type in ICD-9 codes for bites and stings, and as a result, those encounters are reported cumulatively per year **(Figure 1)**. The distribution of incident cases throughout the surveillance period was also stratified by

TABLE 1. Diagnostic Codes to Identify Venomous Bites and Stings

ICD-10	ICD-9	Description
—	989.5	Toxic effect of venom
—	E905.0	Venomous snakes and lizards causing poisoning and toxic reactions
T63.0	—	Toxic effect of snake venom
T63.1	—	Toxic effect of venom of other reptiles
T63.2	—	Toxic effect of venom of scorpion
T63.3	—	Toxic effect of venom of spider
T63.4	—	Toxic effect of venom of other arthropods
T63.5	—	Toxic effect of contact with venomous fish
T63.6	—	Toxic effect of contact with other venomous marine animals
T63.8	—	Toxic effect of contact with other venomous animals
T63.9	—	Toxic effect of contact with unspecified venomous animal

Abbreviation: ICD-10, International Classification of Diseases, 10th Revision; ICD-9, International Classification of Diseases, 9th Revision.

TABLE 2. Demographics and Military Characteristics of Venomous Bite and Sting Cases, Active Component, U.S. Armed Forces[a], 2008–2023

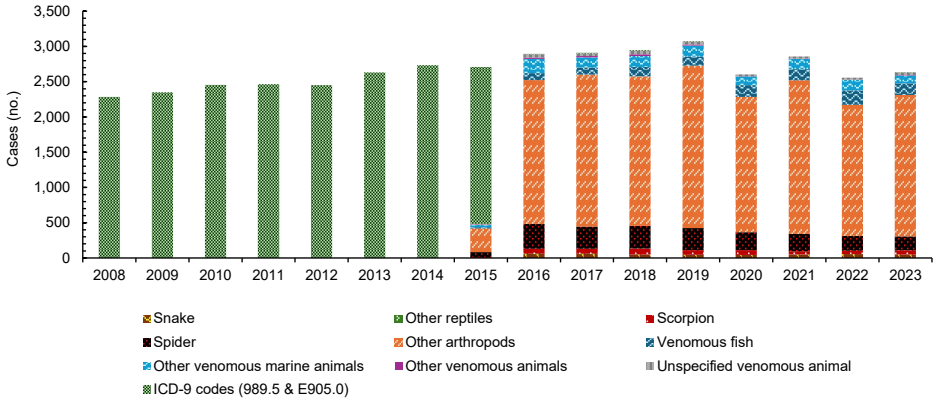
Characteristic	No.	IR (per 10,000 person-years)	IRR	95% CI Lower Limit	95% CI Upper Limit
Total	42,552	19.3			
Sex					
Male	33,887	18.2	Reference	—	—
Female	8,665	25.0	1.4	1.3	1.4
Age, y					
< 20	3,585	24.5	1.3	1.3	1.4
20–24	13,280	19.0	1.0	1.0	1.1
25–29	9,604	18.4	Reference	—	—
30–34	6,486	18.6	1.0	1.0	1.0
35–39	4,973	19.1	1.0	1.0	1.1
40–44	2,859	19.6	1.0	1.0	1.1
45 +	1,765	21.3	1.2	1.1	1.2
Race and ethnicity					
White, non-Hispanic	26,879	20.9	1.4	1.4	1.5
Black, non-Hispanic	5,030	14.5	Reference	—	—
Hispanic	5,657	17.5	1.2	1.2	1.3
Other	4,986	19.8	1.4	1.3	1.4
Service branch					
Army	17,104	21.3	1.6	1.5	1.6
Navy	7,055	13.5	Reference	—	—
Air Force	9,943	19.2	1.4	1.4	1.5
Marine Corps	6,987	23.2	1.7	1.7	1.8
Coast Guard, USPHS	1,463	23.4	1.7	1.6	1.8
Rank					
E1–E4	18,930	20.0	1.1	1.1	1.1
E5–E9	16,300	18.7	Reference	—	—
O1–O3 [W1-W3]	4,458	18.7	1.0	1.0	1.0
O4–O10 [W4-W5]	2,864	19.5	1.1	1.0	1.1
Military occupation					
Combat-specific	6,044	19.7	1.1	1.1	1.1
Motor transport	1,452	20.2	1.1	1.1	1.2
Pilot / air crew	1,484	18.9	1.1	1.0	1.1
Repair / engineering	11,604	18.0	Reference	—	—
Communications / intelligence	8,841	18.6	1.0	1.0	1.1
Veterinarian	520	21.1	1.2	1.1	1.3
Health care	3,655	20.0	1.1	1.1	1.2
Other	8,952	21.2	1.2	1.1	1.2
Combatant command[b]					
NORTHCOM	36,629				
CENTCOM	111				
INDOPACOM	2,407				
EUCOM	1,334				
AFRICOM	7				
SOUTHCOM	91				
Missing or unknown	1,973				

Abbreviations: No., number; IR, incidence rate; IRR, incidence rate ratio; CI, confidence interval; y, years; E, enlisted; O, officer; USPHS, U.S. Public Health Service; NORTHCOM, U.S. Northern Command; CENTCOM, U.S. Central Command; INDOPACOM, U.S. Indo-Pacific Command; EUCOM, U.S. European Command; AFRICOM, U.S. Africa Command; SOUTHCOM, U.S. Southern Command.

[a] Service members were counted once per year.

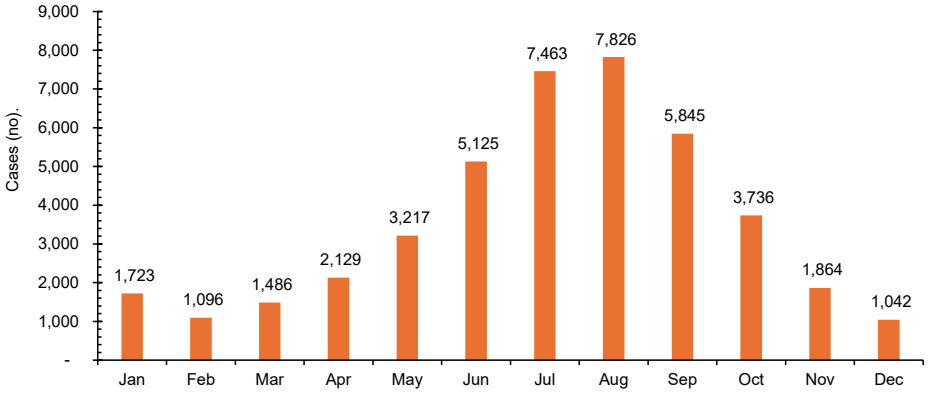
[b] IR and IRR were not calculated for combatant commands, as person-time stratified by combatant command was not available.

FIGURE 1. Annual Incident Cases of Venomous Bite and Sting Cases, by Type of Animal, Active Component U.S. Service Members, 2008–2023[a]



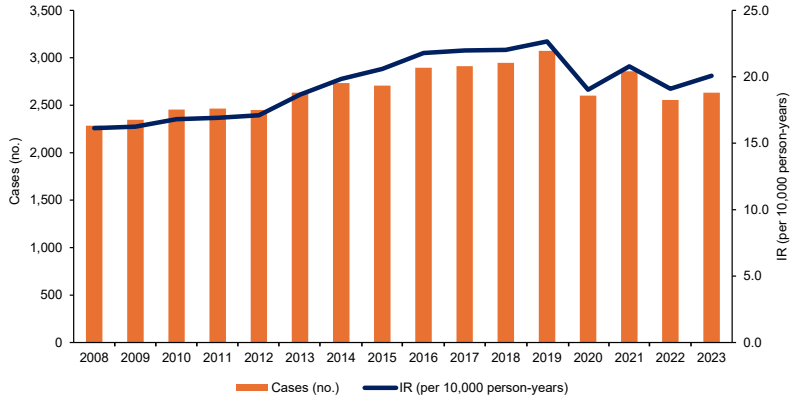
Abbreviations: no., numbers; ICD-9, International Classification of Diseases, 9th Revision; ICD-10, International Classification of Diseases, 10th Revision.
[a] Stratification by animal type only available from Oct. 2015, due to ICD-10 diagnostic coding availability.

FIGURE 2. Total Number of Venomous Bite and Sting Cases by Month, Active Component U.S. Service Members, 2008–2023



Abbreviation: no., numbers.

FIGURE 3. Annual Incidence Rates of Venomous Bite and Sting Cases [a], Active Component U.S. Service Members, 2008–2023



Abbreviations: no., numbers; No., Number; IR, incidence rate.
[a] Service members counted once per year.

month to delineate case seasonality **(Figure 2)**. Most bites and stings occurred in the summer months (June–September), with August producing the greatest number of cases **(Figure 2)**.

Female service members showed an IR of 25 cases per 10,000 p-yrs compared to their male counterparts (18.2 cases per 10,000 p-yrs). Additionally, ACSMs younger than age 20 years had the highest incident rate (24.5 cases per 10,000 p-yrs). IRs were relatively high among non-Hispanic White and enlisted ACSMs **(Table 2)**. The IR was lowest within the Navy (13.5 cases per 10,000 p-yrs), albeit IRs were relatively similar among the other service branches **(Table 2)**.

Temporal analysis revealed a gradual increase in annual IR from 2008 (16.1 cases per 10,000 p-yrs) to a peak in 2019 (22.7 cases per 10,000 p-yrs), with a subsequent slight decrease in the final 4 years **(Figure 3)** of the surveillance period. The lowest and highest average rates occurred during the periods 2008–2012 (16.6 cases per 10,000 p-yrs) and 2016–2019 (22.1 cases per 10,000 p-yrs), respectively. A sharp decline followed the COVID-19 pandemic, dropping from 22.7 cases per 10,000 p-yrs in 2019 to 19.0 cases per 10,000 p-yrs in 2020 **(Figure 3)**.

The study also investigated IRRs to understand animal bite incident disparities within the ACSM population **(Table 2)**. The findings revealed significant differences in risk levels. Compared to men, women had approximately one-third higher risk of animal stings or bites during the period (IRR 1.37, 95% CI 1.3, 1,4). Age also emerged as a significant factor, with ACSMs younger than age 20 years exhibiting a 34% higher risk (IRR 1.3, 95% CI 1.3, 1.4) and those aged 45 years or older showing a 16% higher risk (IRR 1.16, 95% CI 1.1, 1.2) compared to the reference group of ACSMs aged 25-29 years.

Interestingly, occupation also played a role, as veterinarians and veterinary technicians were found 17.0% more likely to sustain an animal bite or sting (IRR 1.2, 95% CI 1.1, 1.3) than the reference group of repair and engineering military specialists **(Table 2)**.

Discussion

Bites and stings from various animals pose a significant risk to ACSMs, with the data from 2008 through 2023 confirming this vulnerability. Although the majority of cases from 2008 through 2023 were among male service members of specific demographic and occupational groups, the IR was, unexpectedly, higher among women. This finding reflects, at least in part, the over-representation of women in veterinary roles (63.0% of veterinarians[14] and 88.0% of veterinary technicians[15] in the U.S. are women), exposing them to increased animal contact and occupational hazards.

The observed peak in IR during 2019 could be attributed to increased outdoor activities and operational tempo, followed by a decline coinciding with the COVID-19 pandemic's impacts on training and deployments. This analysis indicates that the majority of service member bites and stings from animals occur in the U.S., peaking during summer months **(Figure 2)**, when snakes, insects, and other animals are most active.[8-10,16,17] This is coincident with the higher risk faced by ACSMs engaged in warm weather field training exercises in wooded areas, particularly from arachnids such as the Black Widow spider (*Latrodectus mactans*).[17]

Comparison with other published data on the U.S. general population is limited, but it is likely that IRs of venomous animal bites and stings are higher among military personnel due to their increased exposure to high-risk environments.[9] Arthropod envenomation accounts for a higher percentage of morbidity and mortality than snake envenomation among ACSMs[8,10] as well as the civilian population,[3] and medically significant scorpion sting encounters are fourth among ACSMs[10] and account for a high prevalence among the civilian population as well.[16] The estimated global toll from snake bites in the civilian population is substantial, with approximately 5.4 million people bitten by snakes each year, resulting in 1.8–2.7 million cases of envenoming and 81,410–137,880 deaths.[2] Similar to previous findings of venomous snake bites in the military, this analysis also shows venomous stings and bites of ACSMs to be highest in the U.S. compared to other combatant commands.[9]

These report findings have implications for military planning and operations, particularly in regions with high risks of venomous animal encounters. The development of clinical practice guidelines such as the Joint Trauma System's clinical practice guideline training for bites, stings, and envenomation,[6] is crucial in providing comprehensive guidance for snakebite management and reducing risk of complications. Field guides[10,18,19] and clinical practice guidelines[6,20] are available for the U.S. Armed Forces, which offer personal protective measures against snake, marine animal, arthropod, and insect bites and stings to minimize envenomation and prevent diseases with militarily significant effects. These field guides and guidelines identify potentially dangerous animals that bite and sting, describe their biology and characteristics, recognize the symptoms caused by their venom or bites or stings, provide preventive measures, and learn appropriate treatment measures after military service members are bitten or stung.

To reduce risk of envenomation from animals of interest in this study, individuals can take preventive measures such as wearing protective clothing, using insect repellents, and avoiding high-risk areas. Proper training and education on how to identify and avoid venomous animals can also help reduce risk of envenomation. Awareness of one's surroundings and avoiding reaching or stepping into dark or hidden areas can help prevent snake bites and arthropod stings. When in marine environments, protective gear such as wetsuits or booties, in addition to avoidance of touching or handling marine animals, can help prevent marine envenomation. If envenomation occurs, prompt medical attention and appropriate treatment are essential to minimize risk of complications and ensure positive outcomes.

This study's findings underscore the importance of continued education, training, and access to medical care in minimizing risk of bites and stings and ensuring the health and operational readiness of military personnel. These findings also highlight the importance of considering individual characteristics when developing and implementing safety protocols for those working with animals.

One of the limitations of this retrospective report is that some cases of venomous animal bites and stings may not have been reported or documented, potentially leading to under-estimation of true incidence. While the DMSS provides a comprehensive database of medical encounters among military personnel, it may not capture all cases of venomous animal bites and stings, especially in locations outside the U.S., leading to under-reporting. This possible under-reporting could be the contributing factor to the high IR in the U.S combatant commands compared to other locations. Moreover, medical support is readily available within the U.S. compared to other locations, which could result in more U.S. medical encounters regardless of bite or sting allergic reaction severity; ACSMs in locations outside the U.S., including operations, may only seek medical care when they have severe allergic reactions to bites or stings.

Another limitation to the study is the use of diagnostic codes that are prone to coding errors, as well as changes in ICD code changes form ICD-9 to ICD-10 that could lead to differences in incidence. ICD-9 coding for venomous bites and stings does not delineate encounters by type of animal, whereas ICD-10 codes provide details and stratification by animal type. As a result, data from October 2015 onwards provide a clear delineation of impacts by different types of bites and stings, making it easier to determine leading contributors to medical encounters among ACSMs.

Future research should focus on identifying strategies to reduce the incidence of bites and stings, particularly among high-risk groups and those deployed to regions with high risks of venomous animal encounters. The report emphasizes the importance of proper training, education, and access to medical care in minimizing risk of bites and stings and ensuring the health and operational readiness of military personnel. The results of this report also suggest that the military should consider implementing targeted prevention and education programs for service members at high risk of venomous animal bites and stings.

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Potential High Arbovirus Exposure in INDOPACOM During U.S. Service Member Deployment or Exercises in Papua New Guinea

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Arboviruses pose a significant health threat to U.S. military personnel deployed in the U.S. Indo-Pacific Command (INDOPACOM) region. In 2023 we conducted a sero-epidemiological study to determine the arboviruses circulating in 185 Papua New Guinea military personnel (PNGMP), using the neutralizing antibody (NAb) assay. Overall, sero-positivity rates among the 185 PNGMP tested were: anti-Zika virus (ZIKV), 87% (n=161); anti-Japanese encephalitis virus (JEV), 62.2% (n=115); anti-Ross River virus (RRV), 44.3% (n=82); anti-Murray Valley encephalitis virus (MVEV), 39.5% (n=73); anti-chikungunya virus (CHIKV), 33.5% (n=62); anti-Barmah Forest virus (BFV), 10.8% (n=20); and anti-West Nile virus (WNV), 5.9% (n=11). The monotypic NAb sero-positivity rates for dengue virus (DENV) serotypes were: anti-DENV-1 94.6% (n=175), anti-DENV-2 93% (n=172), anti-DENV-3 95.1% (n=176), and anti-DENV-4 31.4% (n=57). These findings indicate that the majority of PNGMP had prior exposure to DENV and ZIKV, with a notable proportion exposed to CHIKV, RRV, JEV, and MVEV, and lower levels of exposure to BFV and WNV. Low or moderate prior exposure may leave individual PNGMP immunologically naïve and more susceptible to infection and disease upon first exposure. Furthermore, secondary DENV infections with a different serotype can increase risk of severe disease due to immune enhancement mechanisms such as antibody-dependent enhancement. Understanding these exposure patterns is crucial for assessing population risk and informing surveillance and prevention strategies. U.S. soldiers exercising or deploying to Papua New Guinea should adhere to strict preventive measures for minimizing mosquito bites and reducing their risk of arboviral infections.

What are the new findings?

To our knowledge, this study provides the first comprehensive examination of arbovirus sero-positivity rates in Papua New Guinea military personnel (PNGMP) following the COVID-19 pandemic. After examining sero-positivity of 11 arboviruses, we found a majority of PNGMP with neutralizing antibodies (NAb) to dengue and Zika viruses, with some NAb to chikungunya, Japanese encephalitis, Ross River, and Murray Valley encephalitis viruses. Sero-prevalence to Barmah Forest and West Nile viruses was less common.

What is the impact on readiness and force health protection?

This study shows the potential circulation of multiple mosquito-borne viruses in Papua New Guinea. The alarmingly high prevalence of arbovirus in tested Papua New Guinea military personnel reveals the significant risk of environmental exposure to mosquito-borne diseases in that country. These study findings indicate the threat posed to U.S. combatant commands operating in the region, illustrating the need for robust preventive measures that minimize bites from infected mosquitoes. Implementation of thorough vector control strategies and personal protective measures will be critical for mitigating existing arbovirus risks for personnel traveling to or exercising in Papua New Guinea.

Arboviral diseases, transmitted by arthropods such as mosquitoes and ticks, are a significant health threat to deployed U.S. military personnel and the U.S. Military Health System (MHS). Arboviruses pose continual risk, and continue to emerge and challenge force health protection. With new outbreaks and evolving vector ecology across the Indo-Pacific region, risk of both endemic and emerging arboviruses remains. Updated sero-surveillance helps to track trends, guide prevention, and strengthen operational readiness.

The U.S. military has a long history of combating arboviral diseases, particularly dengue virus (DENV), Zika virus (ZIKV), and chikungunya virus (CHIKV), with DENV the most prevalent.[1] DENV infections have remained a persistent operational threat to the U.S. military since the Spanish–American War.[1] The first isolation of DENV was achieved by Dr. Albert Sabin in 1944, derived from a U.S. soldier who experienced acute illness while deployed to Papua New Guinea.[2] The original New Guinea C strain of DENV, now known to be a DENV-2 serotype, was followed in the same year by additional isolation, of DENV-1, from another sick soldier stationed in Papua New Guinea.[3]

Papua New Guinea, the world's third largest island country, is located in the Southwest Pacific, within the U.S. Indo-Pacific Command (INDOPACOM) area of responsibility. During World War II (WWII), Papua New Guinea was a crucial operational theater for the war in the Pacific, with a Japanese invasion in 1942 and subsequent Allied campaign—of primarily

Australian and American forces—trying to expel the Japanese. A significant number of mosquito-borne pathogen infections were reported among active Allied troops during WWII after deployment to Papua New Guinea,[1,4] with DENV disease one of the major causes of morbidity among soldiers.[5]

Recently, U.S. military presence in Papua New Guinea has increased, with several multi-national, joint exercises conducted in response to strategic pressures arising from the expansion of China's military presence in the Southwest Pacific. Surveillance conducted in Papua New Guinea in 2019 revealed a high prevalence rate of ZIKV and moderate CHIKV infections among Papua New Guinea military personnel (PNGMP) located at Manus Island and Wewak barracks.[6-8] ZIKV and CHIKV diseases are the second and third most significant arboviral disease threats to U.S. military, particularly during deployments to high-risk regions.[5] *Aedes* mosquitoes, the primary vector transmitting ZIKV, are found in nearly 200 U.S. military installations worldwide. From January 1, 2013 through December 31, 2022, 212 ZIKV cases were reported among U.S. service members, based on data from the Disease Reporting System internet and laboratory records from the Composite Healthcare System.[9] Meanwhile, CHIKV cases within the MHS are increasing, with a significant proportion of those infected experiencing long-term rheumatic complications.[10]

Other arboviruses such as Ross River virus (RRV), Barmah Forest virus (BFV), Japanese encephalitis virus (JEV), and Murray Valley encephalitis virus (MVEV) infections have also been reported in Papua New Guinea.[11,12] RRV and BFV, both considered typical Australian arboviruses, are the leading causes of human arboviral diseases in that country,[13] which is less than 100 miles south of Papua New Guinea. JEV and MVEV are endemic in Papua New Guinea and northern Australia.[14] In 2016 and 2017, RRV and BFV outbreaks occurred among Australian Defence Force (ADF) personnel in the Shoalwater Bay Training Area of Queensland, in northern Australia.[15,16] A joint training exercise in 1997 resulted in at least 8 U.S. service members contracting RRV among approximately 9,000 U.S. marines and Australian soldiers participating in ground exercises in Queensland.[17] In 2022, a JEV outbreak in Australia resulted in 45 reported cases and 7 deaths. No new human cases of JEV were recorded in Australia from December 2022 until December 2024, when a JEV case was reported in Victoria, in southern Australia. Although the origin of the outbreak remains uncertain, it is believed that migratory birds or wind-blown mosquitoes may have introduced JEV from Papua New Guinea to Australia.[18]

There are a few licensed vaccines currently available for arboviruses, and those that are available carry several caveats. The CHIKV vaccine, Ixchiq, approved by the U.S. Food and Drug Administration in 2023, is not yet widely licensed in other countries. For DENV, Dengvaxia (CYD-TDV) is approved in several countries but is only recommended for individuals ages 9-45 years with confirmed prior dengue infection. Due to the risk of severe disease in seronegative recipients, Dengvaxia is not ideal for broad public health use. In contrast, safe and effective vaccines that have long existed for JEV and yellow fever virus (YFV) are included in routine immunization programs in endemic regions.

For many other medically important arboviruses—including ZIKV, RRV, and MVEV—no licensed human vaccines currently exist, highlighting a significant gap in global prevention efforts. Furthermore, there are no specific anti-arboviral treatments for those diseases; clinical management primarily focuses on symptom relief.

Prevention of mosquito-borne arboviral diseases largely relies on personal protective measures, including long-sleeved uniforms, bed nets, permethrin treatment of uniforms and nets, and DEET (N,N-diethyl-meta-toluamide)-based mosquito repellents. Given the widespread presence of mosquito vectors in tropical and subtropical areas, arboviruses will likely continue to spread beyond their original regions of discovery, making force health protection in INDOPACOM increasingly challenging.

Use of antibody testing methods such as ELISA (enzyme-linked immunosorbent assay) for determining arbovirus exposure for surveillance is becoming a significant challenge due to broad cross-reactivity among the alphavirus and flavivirus families co-circulating in the same area.[19] Risk of co-infection further complicates serological interpretation.

Although a few serological studies—most conducted in the 1970s—have documented arbovirus exposure and outbreaks in Papua New Guinea, in addition to our own surveillance efforts in 2019, comprehensive epidemiological data remain limited due to lack of diagnostic capacity, inconsistent clinical case reporting, and weak surveillance infrastructure in much of Papua New Guinea. The COVID-19 pandemic placed additional strain on Papua New Guinea health systems. As a result, the true distribution, burden, and temporal trends of arboviral diseases in Papua New Guinea remain incompletely defined.

This study aims to address this important gap in data from Papua New Guinea by providing updated arbovirus serology data from PNGMP stationed at Lae Barracks on the country's eastern coast **(Figure 1)**. We measured neutralizing antibodies (NAb) against key arboviruses in this population. Our 2019 survey found high ZIKV and moderate RRV and CHIKV exposure at Wewak and Manus barracks. This follow-up study evaluates whether exposure patterns have shifted, especially post-COVID-19 pandemic.

Methods

The study was approved by the Papua New Guinea Medical Research Advisory Committee (MRAC, no. 18-21) and the Department of Australian Defence and Veteran Affairs Human Research Ethics Committee (DDVA HREC, no. 084-18, no. 157-19). Written informed consent was obtained from all participants.

Study Population Demographics

This study was part of an infectious disease surveillance program conducted by the ADF in conjunction with the Papua New Guinea Defence Force. A total of 185 PNGMP from Lae Barracks were recruited between April 20, 2023 and May 9, 2023. A convenience sample of serum specimens

from PNGMP present at Lae Barracks during this period was collected. Participants provided written informed consent for additional infectious disease testing. Additional demographic and exposure data, including serum collection dates, age, sex, travel and vaccination history, and mosquito bite prevention measures, were self-reported via a study questionnaire. Due to security requirements, information on military occupational specialty, rank, and deployment history were not collected. The age range of participants was 24–60 years, with a median age of 35 years. The largest participant age group was 30-39 years (38.9%, n=72), followed by 20-29 years (27%, n=50). The cohort was predominantly male (96.2%, n=178). Forty-two participants reported domestic travel (22.7%), primarily to the capital, Port Moresby, or East or West Highlands regions. Ninety-nine participants (53.5%) reported travel history to Australia, but only 11 (5.9%) had traveled to Australia within 3 months prior to blood collection. All participants were asymptomatic at the time of blood withdrawal, with no reported history of prior infectious disease infections and outcomes, and no reported prior vaccination for JEV and YFV. Demographic features and mosquito prevention practices reported by survey respondents are summarized in **Table 1**.

All serum samples were bar-coded, stored at -20°C and transported to Brisbane, Australia for neutralization analysis against the arbovirus strains as detailed in the **Supplementary Table.**

Cells, Viruses and NAb Assays

Vero cells (African green monkey kidney epithelial cells) and C6/36 mosquito cells were routinely cultured in the laboratory and used for micro-neutralization assays. The arboviral strains used for NAb assays in this study are listed in the **Supplementary Table.** The virus stock preparation and serum NAb titers were assessed using a micro-neutralization assay and modified according to methods previously described.[6-8] NAb titer greater than or equal to 20 for flaviviruses and greater than or equal to 10 for alphaviruses were considered positive.

FIGURE 1. Location of Serological Survey of Papua New Guinea Military Personnel, 2023

Asterisk (★) indicates location of Lae Barracks, Lae, Papua New Guinea.

Statistical Analysis

Data analysis was performed using GraphPad version 9.0 and an online Chi-square test calculator (https://www.socscistatistics.com/tests/chisquare2/default2.aspx) to compare the arbovirus sero-positivity proportions among different age groups. *P*-values less than or equal to 0.05 were considered statistically significant.

Results

Sero-Prevalence Determined by Pathogen-specific NAb

As shown in **Table 2** and **Figures 2–4**, the 2023 PNGMP cohort exhibited very high sero-prevalence for DENV-1 (95%, n=175), DENV-2 (93%, n=172), and DENV-3 (95.1%, n=176), indicating widespread exposure or cross-reactivity NAbs among these serotypes. Mean NAb titers were also high for DENV-2–4, suggesting stronger or more frequent immune responses. Lower DENV-4 sero-prevalence (31%, n=57), with a significantly lower mean titer of 79.0, suggests that this serotype may be less commonly circulating or elicits a weaker immune response in this population. ZIKV was also prominent, with high sero-prevalence (87%, n=161) and a strong mean titer of 265.1, while JEV was also notable, with 62.2% (n=115) positivity and mean titer of 126.3. CHIKV (33.5%, n=62), RRV (44.3%, n=82), and MVEV (39.5%, n=73) showed moderate sero-positivity, indicating endemic but less dominant circulation. WNV (5.9%, n=11) and BFV (10.8%, n=20) demonstrated low sero-prevalence, suggesting either minimal exposure or low transmission rates in the study population. These findings reveal a high level of DENV and ZIKV exposure in PNGMP, with a still notable proportion exposed to CHIKV, RRV, JEV, and MVEV, and lower exposures to BFV and WNV.

In a Chi-square analysis, the sero-prevalence of RRV, CHIKV, DENV1-4, ZIKV, MVEV, and JEV did not significantly differ by age group **(Table 2)**. Due to the low

sero-prevalence of BFV and WNV, NAb sero-positivity rates were not compared by age groups. Sex-stratified analysis was not conducted due to the predominantly male study population.

Multiple NAb Positivity Among Alphavirus

Among alphaviruses, dual or multiple NAb sero-positivity patterns were observed: BFV$^+$/ CHIKV$^+$ in 3 cases (1.6%), BFV$^+$/ RRV$^+$ in 5 cases (2.7%), CHIKV$^+$/ RRV$^+$ in 34 cases (18.3%), and triple positivity BFV$^+$/ CHIKV$^+$/ RRV$^+$ in 7 cases (3.8%) (data not shown).

Multiple NAb Positivity Among Dengue Virus and Flavivirus

As shown in **Table 3**, nearly one-third (28.1%) of PNGMP in 2023 had pan-serotype immunity, or positivity to all 4 DENV serotypes. Moreover, 64.3% of participants were positive to 3 serotypes, suggesting multiple past infections or strong cross-reactive responses, likely due to co-circulation or sequential infections with different serotypes. Only a small fraction (5.4%) was positive to only 1 or 2 serotypes, and 2.2% were negative for all 4, indicating minimal or no prior DENV exposure in this subset.

A significant majority (92.9%) of study participants were sero-positive to 4 or more flaviviruses **(Table 4)**, indicating an extensive exposure or high cross-reactive antibody responses. The largest groups consisted of individuals positive to 6 (31.4%) or 5 (30.3%) flaviviruses, reflecting multi-flavivirus circulation or repeated exposures. Only a small minority (5.9%) were positive to 3 or fewer flaviviruses, suggesting limited exposure in only this small portion of the participant population. Notably, 2 individuals (1.1%) were sero-positive to all 8 flaviviruses tested, suggesting either uncommonly broad exposure histories or high cross-reactivity of their serum antibodies.

These data indicate a high burden of arbovirus transmission or immunological imprinting in the region, consistent with the co-endemicity of multiple flaviviruses and alphaviruses such as DENV, ZIKV, RRV, CHIKV, JEV, MVEV, and WNV.

TABLE 1. Demographic Features and Mosquito Prevention Practices Reported for Papua New Guinea Military Study Participants

	No.	%
Total Blood Donors	185	100
Age, y		
20–29	50	27.0
30–39	72	38.9
40–49	25	13.5
≥50	38	20.5
Sex		
Male	178	96.2
Female	7	3.8
Travel		
Domestic	42	22.7
Overseas (3 months before blood withdrawal)	11	5.9
Australia	99	53.5
Mosquito prevention measures		
Mosquito coils	0	0.0
Screens	19	10.3
Mosquito bed net	98	53.0
House insecticide spray	108	58.4
Long sleeves	27	14.6
Combined	175	94.6
Vaccination against arboviruses (% of total)		
JEV and YFV	0	0.0

Abbreviations: y, years; JEV, Japanese encephalitis virus; YFV, yellow fever virus.

Discussion

Arboviral infections represent substantial and ongoing threats to the operational readiness of U.S. military personnel deployed to endemic regions such as Papua New Guinea. These results, demonstrating high arbovirus sero-positivity and co-positivity rates among PNGMP in 2023, re-affirm that Papua New Guinea is a highly endemic area for multiple arboviruses. These findings have important implications for U.S. forces deployed under the recently expanded defense cooperation agreements between the U.S., Australia, and Papua New Guinea.

At the Lae Barracks in 2023, PNGMP exhibited extremely high DENV sero-positivity, with 98% of participants demonstrating NAb reactivity to at least 1 DENV serotype. The most frequently co-detected serotypes were DENV-1, DENV-2, and DENV-3, with DENV-4 showing the lowest prevalence. This distribution aligns with historical data indicating the persistent endemic circulation of DENV-1–3 in PNG and lower levels of DENV-4 introduction into Australia from Papua New Guinea from 1999 through 2020.[20-22]

Accurate interpretation of DENV NAb results in hyper-endemic regions such as Papua New Guinea is complicated by repeated exposures to multiple DENV serotypes. Primary DENV infection provides life-long immunity to the infecting serotype virus but only transient, partial protection against the other 3 serotypes.[23] Secondary infections often result in broad, cross-reactive NAb responses that can persist long-term.[24] Moreover, other endemic flaviviruses in Papua New Guinea, including ZIKV, JEV, WNV, and MVEV, can also cross-react with DENV in NAb assays,

TABLE 2. Arbovirus Neutralizing Antibody Positivity[a] Among Different Papua New Guinea Military Participants Before 2023

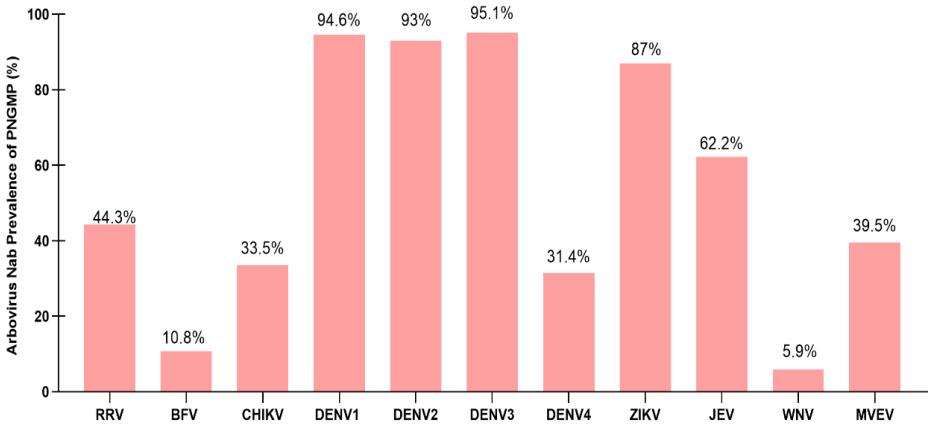
Virus		Total Positivity				Positivity by Age Group								
		All Samples (n=185)				20–29 (n=50)		30–39 (n=72)		40–49 (n=25)		≥50 (n=38)		Chi Square
		No.	%	Mean NAb Titer	95% CI	No.	%	No.	%	No.	%	No.	%	*p*-value
Flavivirus														
DENV group	DENV-1	175	94.6	303.9	271.0–336.8	46	92.0	68	94.4	24	96.0	37	97.4	0.998
	DENV-2	172	93.0	362.9	327.0–398.8	46	92.0	66	91.7	23	92.0	37	97.4	0.997
	DENV-3	176	95.1	226.5	195.8–257.2	46	92.0	67	93.1	25	100	38	100	0.122
	DENV-4	57	31.4	79.0	55.7–102.2	12	24.0	26	36.1	8	32.0	12	31.6	0.782
JEV group	JEV	115	62.2	126.3	93.4–159.2	27	54.0	48	66.7	17	68.0	23	60.5	0.9
	WNV	11	5.9	30.9	14.6–47.2	2	4.0	4	5.6	0	0.0	5	13.2	N.D
	MVEV	73	39.5	46.6	34.9–58.3	22	44.0	26	36.1	9	36.0	15	39.5	0.944
Spondweni group	ZIKV	161	87.0	265.1	228.2–301.9	41	82.0	62	86.1	24	96.0	34	89.5	0.215
Alphavirus														
	RRV	82	44.3	193.9	146.8–241.0	18	36.0	30	41.7	14	56.0	20	52.6	0.673
	CHIKV	62	33.5	89.2	52.5–125.9	15	30.0	20	27.8	14	56.0	13	34.2	0.373
	BFV	20	10.8	202.5	86.6–318.4	4	8.0	7	9.7	1	4.0	8	21.1	N.D.

Abbreviations: n, number; No., number; NAb, Neutralizing antibody; CI, confidence interval; DENV, dengue virus; JEV, Japanese encephalitis virus; WNV, West Nile virus; N.D., not done; MVEV, Murray Valley encephalitis virus; ZIKV, Zika virus; RRV, Ross River virus; CHIKV, chikungunya virus; BFV, Bahmah Forest virus.
[a]NAb titer ≥20 was considered 'positive' for flaviviruses; NAb titer ≥10 was considered 'positive' for alphaviruses.

further complicating serological interpretation.[25] Therefore, it is difficult to determine true viral exposure using the traditional greater than or equal to (≥) 4-fold NAb titer difference between real infection virus and its cross-reaction virus, as many PNGMP samples exhibited high NAb titers against multiple DENV serotypes and other flavivirus, mainly ZIKV.

Nevertheless, the high sero-positivity strongly suggests the ongoing co-circulation and repeated DENV exposure in this population. The risk of secondary DENV infections, which are associated with more severe disease through antibody-dependent enhancement (ADE), remains a concern in populations with high prior exposure. The apparent lack of reported severe dengue cases among PNGMP, however, may indicate that a substantial proportion of infections are asymptomatic or present only with mild, non-specific symptoms.

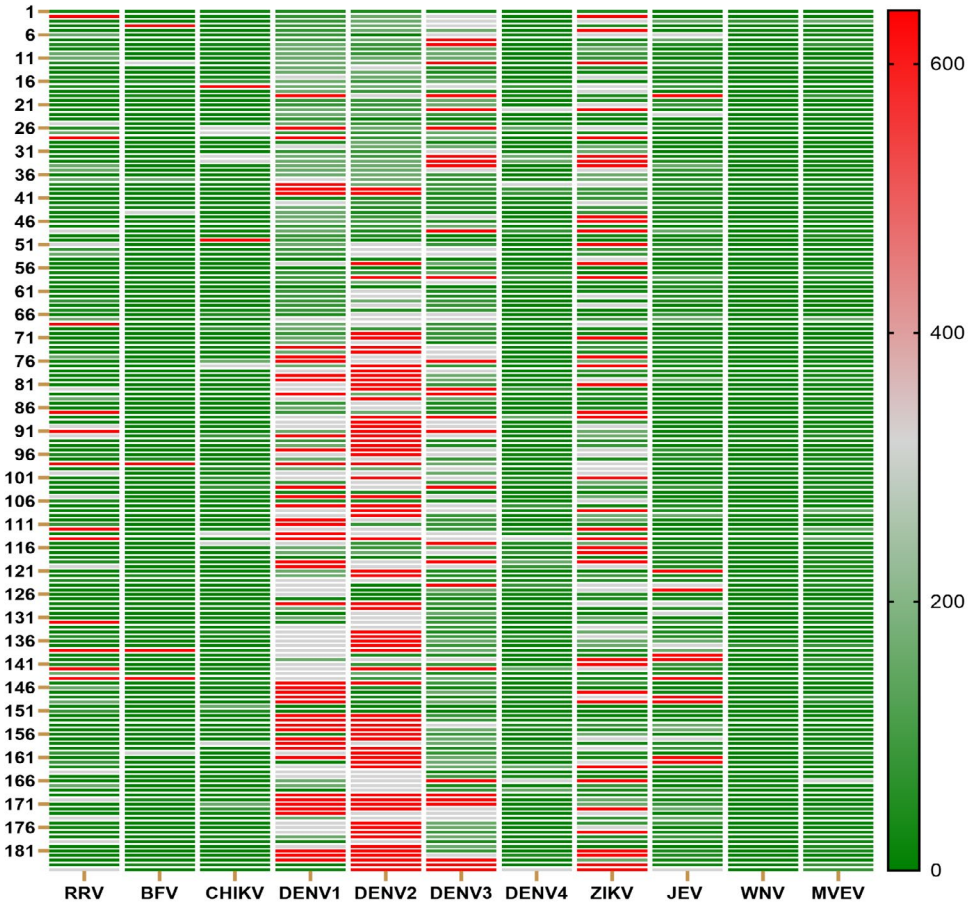
FIGURE 2. Arbovirus Sero-Prevalence[a] Among Papua New Guinea Military Personnel[b] Based on Neutralizing Antibody Assays, 2023



Abbreviations: NAb, neutralizing antibody; PNGMP, Papua New Guinea military personnel; RRV, Ross River virus; Barmah Forest virus; CHIKV, chikungunya virus; DENV, dengue virus; ZIKV, Zika virus; JEV, Japanese encephalitis virus; WNV, West Nile virus; MVEV, Murray Valley encephalitis virus.

[a]NAb titer ≥20 for flaviviruses, ≥10 for alphaviruses were considered positive.
[b]Samples (n=185) from Papua New Guinea military personnel (PNGMP) stationed at Lae Barracks, 2023, tested for neutralizing antibodies (NAb) against 11 endemic and emerging arboviruses.

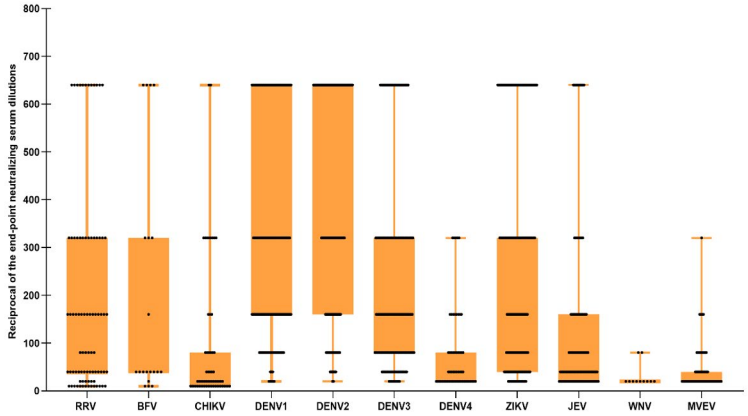
FIGURE 3. Heatmap Representation[a] of Neutralizing Antibody Titers in Papua New Guinea Military Personnel, 2023



Abbreviations: RRV, Ross River virus; Barmah Forest virus; CHIKV, chikungunya virus; DENV, dengue virus; ZIKV, Zika virus; JEV, Japanese encephalitis virus; WNV, West Nile virus; MVEV, Murray Valley encephalitis virus.

[a] Each row corresponds to a test virus, and each column represents an individual patient. Color intensity reflects Nab titer levels.

FIGURE 4. Box Plots[a] Illustrating Neutralizing Antibody Titers for 11 Arboviruses Tested in Papua New Guinea Military Personnel, 2023



Abbreviations: RRV, Ross River virus; BFV, Barmah Forest virus; CHIKV, chikungunya virus; DENV, dengue virus; ZIKV, Zika virus; JEV, Japanese encephalitis virus; WNV, West Nile virus; MVEV, Murray Valley encephalitis virus.

[a] The y-axis represents the reciprocal end-point neutralizing serum dilutions. Box plots show the median (horizontal line) and minimum to maximum of neutralizing antibody titers. All positive serum samples are included.

Asymptomatic or sub-clinical infections represent the majority of DENV infections, particularly in endemic settings, and under-reporting or mis-classification of mild cases as malaria or undifferentiated febrile illness may also contribute to this observation. These findings underscore the importance of paired serological and clinical surveillance to fully understand the burden of disease and guide appropriate preventive strategies in PNGMP.[26]

High ZIKV Nab sero-positivity (87%) among PNGMP 2023 at Lae Barracks shows no statistically significant difference compared to the 2019 survey of PNGMP (65%) at Wewak and Manus Island barracks prior to the COVID-19 pandemic. This prevalence aligns with the high level of ZIKV sero-prevalence (49-63%) in Polynesia, which includes endemic regions,[27] and is significantly higher than the 15.6% average reported across the broader Western Pacific.[28] The elevated prevalence among PNGMP likely reflects increased exposure risks due to greater contact with mosquito habitats during field operations, higher endemicity in deployment locations, or insufficient use of personal protective measures. This underscores the need for targeted vector control, health education, and operational adjustments to reduce transmission risk and protect force health.

Despite widespread ZIKV exposure among PNGMP, our literature review found no reports of congenital ZIKV syndrome (CZS) in Papua New Guinea, possibly due to limited diagnostic capabilities and under-reporting in the country. Additionally, time of exposure may play an important role, as the highest risk of CZS occurs in the first trimester of pregnancy. Cross-immunological protection afforded by high levels of DENV immunity has also been identified as a contributor to reduce CZS development.[29,30] The predominantly young adult male PNGMP cohort may not reflect exposure or infection rates among pregnant women, who are at greatest risk for CZS.

Similarly, CHIKV NAb sero-positivity (33.5%) among PNGMP mirrors rates observed in 2019, suggesting sustained, low level CHIKV endemicity following the 2012 Papua New Guinea outbreak. Cases of CHIKV imported to Australia from Papua New Guinea from 2016 to 2020 evidence

TABLE 3. Dengue Virus Neutralizing Antibody Multi-Seropositivity Among 185 Participating Papua New Guinea Military Personnel, 2023

Number of Positive DENV Serotypes	Number of Participants	
	No.	%
Positive to all 4 serotypes	52	28.1
Positive to 3 serotypes	119	64.3
Positive to 2 serotypes	6	3.2
Positive to 1 serotype	4	2.2
Positive to at least 1 serotype	181	97.8
Negative to all serotypes	4	2.2

Abbreviations: DENV, dengue virus; No., number.

TABLE 4. Multi-Seropositivity to Flaviviruses Among Participating Papua New Guinea Military Personnel (n=185), 2023

Number of Positive Flaviviruses	Number of Participants	
	No.	%
Positive to 8 flaviviruses	2	1.1
Positive to 7 flaviviruses	17	9.2
Positive to 6 flaviviruses	58	31.4
Positive to 5 flaviviruses	56	30.3
Positive to 4 flaviviruses	39	21.1
Positive to 3 flaviviruses	5	2.7
Positive to 2 flaviviruses	1	0.5
Positive to 1 flavivirus	5	2.7
Positive to 0 flaviviruses	2	1.1

Abbreviation: no., number.

Papua New Guinea's role as a persistent source of CHIKV transmission risk.[8,31,32]

Sero-prevalence data also confirm ongoing exposure of PNGMP to other arboviruses historically reported in Papua New Guinea—including RRV, BFV, JEV, WNV, and MVEV—with no significant variation by age, reflecting sustained transmission or early life exposure.

A key strength of this study is the use of the gold standard NAb assay to detect virus-specific antibodies, which correlate strongly with immune protection. While NAb assays cannot distinguish antibody isotypes (IgM vs. IgG)[33] and may retain low level cross-reactivity among related arboviruses, they remain the most reliable serological method. Cross-neutralizing antibodies between DENV and ZIKV are widely documented, with repeated DENV-exposed individuals often exhibiting stronger and more durable cross-neutralizing responses to ZIKV. Similarly, ZIKV infection can induce cross-neutralizing antibodies against DENV, but the extent and duration of this effect can vary.[25] To minimize false positives from cross-reactivity, we applied a conservative sero-positivity limit of greater than or equal to (≥) 1:20 NAb titer for flaviviruses, although precise exposure determination remains challenging in hyper-endemic settings like Papua New Guinea.

These findings have critical implications for U.S. military personnel deployed in Papua New Guinea. Personnel without prior exposure or natural immunity face heightened risks of infection and severe disease, particularly for arboviruses such as DENV, ZIKV, and CHIKV. Asymptomatic or mildly symptomatic infected personnel could inadvertently export arboviruses to other regions with competent vector populations, echoing the past global ZIKV and CHIKV outbreaks.

Given these risks, continuous arboviral and clinical surveillance among military and local populations is essential for detecting symptomatic and asymptomatic infections. Surveillance should also be complemented by entomological monitoring to track spatio-temporal changes in mosquito populations, including species diversity, vector competence, biting behavior, longevity, and dispersal capacity. Environmental factors such as rainfall and temperature, which influence mosquito breeding and activity, as well as zoonotic and sylvatic surveillance, for spillover risk detection, must be integrated for comprehensive risk assessment.

Expanded studies with larger, more demographically diverse cohorts and application of more specific serological assays (e.g., epitope-based ELISAs) will further clarify exposure patterns and guide force health protection measures. Although this study focused on PNGMP, it provides a valuable insight into the endemic risk landscape facing deployed U.S. forces. The endemic and emerging arboviruses circulating in Papua New Guinea pose a sustained threat to U.S. military readiness in this strategically important region. Proactive surveillance, force health education, vector control strategies, and vaccination will be essential to mitigate the risks and safeguard deployed personnel.

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Disclaimers

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policies or positions of their affiliated institutions.

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SUPPLEMENTARY TABLE. Arboviral Strains Used for Neutralization Assay in this Study

Name	Strain	Genbank No.
Barmah Forest virus	BH2193	NC_001786
Chikungunya virus	Reunion strain	DQ443544
Ross River virus	QML strain	GQ433354
Dengue virus 1	Hawaii	KM204119
Dengue virus 2	NGC	M29095.1
Dengue virus 3	H-87	M93130.1
Dengue virus 4	H-241	AY947539.1
Japanese encephalitis virus	Nakayama	EF571853.1
West Nile virus (Kunjin subtype)	MRM61C	KX394398.1
Murray Valley encephalitis virus	MK6684	KF751869

Abbreviation: No., number.

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Historical Perspective

Early U.S. Military Immunization Against Tetanus and Diphtheria: Historical Context and Current Importance

G. Dennis Shanks, MD, MPH

Prior to the Second World War, toxoid immunizations for both tetanus and diphtheria had been developed but were not widely used in adults. Starting in 1941, however, the U.S. Army began extensive immunization with tetanus toxoid. Tetanus decreased dramatically, with only 12 tetanus cases (1 case per million) developing during the war, mostly in imperfectly immunized soldiers. Diphtheria immunization was more complicated, as many adults in 1941 had some natural anti-toxic immunity to diphtheria. A decision to not immunize the U.S. military against diphtheria was made due to low prevalence of the disease and high rates of adverse events. During the war, however, unexpectedly high rates of debilitating cutaneous diphtheria were seen in desert and jungle warfare, among prisoners of war, and amid epidemics of respiratory diphtheria in Europe. Those diphtheria cases resulted in the requirement for U.S. soldiers to be immunized starting in 1945. Adjusted toxoid doses post-war eventually arrived at an accepted dual toxoid regimen. Mass immunization remains the best prevention against diphtheria.

It was rather a surprise to learn that diphtheria was an important and widely prevalent tropical disease.[1] 1946

Vaccination of the U.S. Army began during the War of 1812, with Jennerian smallpox immunization substituting for variolation. A century elapsed before a second vaccine, for typhoid immunization of soldiers, began in 1912, following the Spanish American War.[2]

The third standard U.S. Army immunization was tetanus toxoid, a chemically inactivated toxin that is immunogenic but not toxic. Vaccination of U.S. Army personnel with tetanus toxoid began in 1941, in the months preceding U.S. involvement in World War II. This immunization program resulted from successful tetanus toxoid reports from the British and French armies, with approval requiring nearly a year of effort by the U.S. Army Surgeon General's Office.[3]

Due to the low prevalence of respiratory diphtheria at the beginning of World War II, immunizing the U.S. Army with diphtheria toxoid, although medically possible, was determined to be militarily impractical.[3,4] The decision not to immunize the U.S. Army of the Second World War against diphtheria toxoid was a practical, short-term measure with negative consequences. Surprisingly large numbers of soldiers in both the North African desert and South Pacific jungles were incapacitated by chronic skin ulcers caused by *Corynebacterium diphtheriae*, and over 120 U.S. Army deaths were directly attributed to respiratory diphtheria. Ultimately, immunization against diphtheria was begun in 1945, due to large European diphtheria epidemics.[5,6]

Tetanus

Tetanus was a major military problem in the trenches of the First World War, requiring literally millions of doses of equine anti-toxin for the wounded.[9] The development of tetanus toxoid immunization in the 1920s was a technological breakthrough, allowing individuals to produce their own antisera. Wound prophylaxis against tetanus became toxoid boosting and not equine antisera. Purification of the immunogen to eliminate peptone products used in bacterial culture eliminated some allergic reactions[3]; this was in an era before randomized clinical trials, with evidence of efficacy largely based on comparison groups.

With the onset of another global war, the U.S. Army authorized tetanus toxoid in 1941 for overseas service, and then for all troops, after a year's discussion of the proposed policy change.[2,3] Despite logistical challenges, vaccination of millions of soldiers with tetanus toxoid was largely accomplished with few problems or adverse events **(Figure 1)**. The U.S. Army had 70 tetanus cases per million soldiers in the First World War compared to only 12 cases, most not fully immunized, or 1 per million soldiers, during the Second World War.[3]

The U.S. military problem of tetanus during World War II was largely solved by consistent toxoid immunization of the entire population.[2,4] As neither the German nor Japanese Armies routinely immunized against tetanus, most clinical tetanus during the Second World War occurred in prisoners of war. During the fighting around Manila in 1945, 473 tetanus cases, with 389 deaths, were described in Japanese Army prisoners, but none occurred in wounded U.S. soldiers.[3] The Japanese Army belatedly attempted to develop its own

tetanus vaccine in Jakarta, but inadequate inactivation of the toxin resulted in 900 iatrogenic deaths in Indonesians who served as unwilling product recipients.[10]

Diphtheria

Diphtheria toxoid had been developed in the 1920s and successfully prevented pediatric disease, as well as decreasing need for equine anti-diphtheria toxin. Respiratory circulation of toxigenic *C. diphtheriae* meant that in 1940 many U.S. adults had some immunity, as measured by the intradermal Schick test. Negative Schick results denoted an ability to neutralize a small intradermal dose of diphtheria toxin; positive tests indicated skin reactions with no antibody neutralization.[11]

On the basis of Schick testing of 3,000 soldiers, in 1940 the U.S. Army calculated that a majority (55%) of soldiers already had some pre-existing diphtheria immunity.[3] Mass screening of soldiers with Schick tests was decided to be medically possible but militarily impractical.[4]

Diphtheria vaccination was much more complex than tetanus vaccination, despite similarities in toxoid technology. Schick-negative individuals (i.e., with diphtheria antibodies) often had adverse reactions when immunized with diphtheria toxin, contributing to the resistance to mass vaccination of soldiers. Adverse events in Schick-negative soldiers included swollen arms and lost duty days, with hospitalization of several who were immunized.

This weighing of risks versus benefits was reasonable, based on the information available at the time, but it assumed a static environment, which is not typical of infectious disease epidemiology during war. There were only 122 cases of respiratory diphtheria in the U.S. Army in 1942, but by 1945 cases had increased to 3,455, mostly in Europe.[3] Mortality in the U.S. Army also markedly increased, with 86 of 125 total diphtheria deaths in 1945 occurring overseas.[3]

During the war, epidemics of cutaneous diphtheria in soldiers in austere environments, such as the deserts of North Africa and jungles of the Southern Pacific, were occurring.[1,16] Desert or veldt sore was a diagnosis well-known from the First World War and returned to be problem during the Second World War, initially in the British Army in Palestine and then in the U.S. Army in the Pacific.[16-18] Chronic, debilitating ulcers resulted from toxigenic skin infections that healed very slowly. Some soldiers were removed from duty for months of rehabilitation due to chronic foot ulcers and had to be evacuated to specialist tropical disease hospitals in the U.S. **(Figure 3)**.

Cutaneous diphtheria was probably the worst in Allied prisoner of war camps (PoW) in Asia, where debilitating tropical skin ulcers, compounded by starvation and other infections, often began a downward cycle to prisoner demise.[19] German PoW camps in the U.S. and U.K. also had problems with cutaneous diphtheria in unimmunized prisoners.[20]

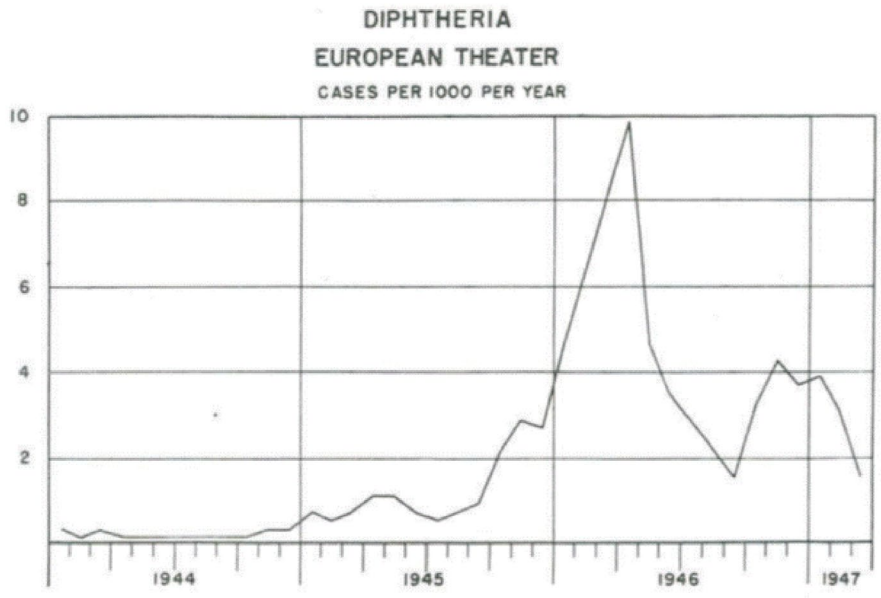
The massive, war-associated diphtheria epidemics during the Second World War led the U.S. Army to institute diphtheria toxoid vaccine in 1945 after Schick testing occupation soldiers, and then their families, in Germany.[13] Post-war diphtheria rates in the U.S. Army approached 10 per 1,000 per year in 1946, when diphtheria accounted for 15% of all medical deaths and 45% of all infectious disease deaths **(Figure 2)**.[14]

FIGURE 1. Army Nurse Immunizes U.S. Soldier, Probably Against Tetanus, Queensland, Australia, 1942

Universal immunization against diphtheria in the U.S. military did not occur with mass Schick testing, but instead resulted from decreased immunogen in the standard combined tetanus-diphtheria toxoid vaccine (dT). The new formulation was accomplished by a series of studies among U.S. Navy recruits at Great Lakes Training Center.[12,15]

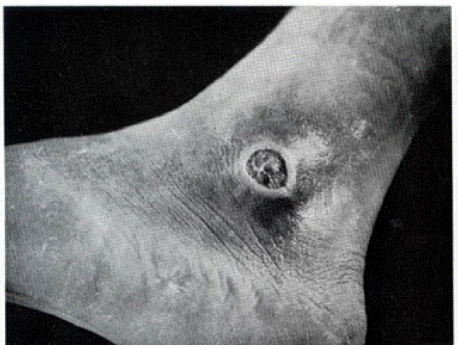
Pharyngeal diphtheria, leading to systemic intoxication and potentially lethal myocarditis and neuritis, was effectively

FIGURE 2. Incidence of Respiratory Diphtheria in the U.S. Army, Europe, 1944–1947[a]



[a] Cases illustrated per 1,000 soldiers.

FIGURE 3. Chronic Skin Lesion Typical of *Corynebacterium diphtheriae,* U.S. Army Soldier Evacuated from Solomon Islands



prevented by immunization and largely ceased to be a problem as universal dT immunizations became the standard both in children and adults after World War II.[2]

Commentary

Immunization with established toxoid vaccines eventually solved the military problem of exposure to toxigenic environmental bacteria. During the First World War, tetanus was a greatly feared disease that resulted from battlefield wounds. Nearly all medical officers had some experience with the often lethal disease.[9] The opportunity to dispense with reactogenic equine antisera and introduce tetanus toxoid immunization was embraced by Army leadership. Although general tetanus immunization of the U.S. Army began in the months before U.S. entry into the Second World War, requirements for diphtheria vaccination were more complicated, and were delayed due to adverse events and difficulty with mass Schick testing of soldiers during mobilization.

The delay against universal diphtheria immunization during World War II had 2 adverse consequences: 1) hundreds of frontline infantry soldiers in both Africa and Asia were incapacitated by chronic skin ulcers that healed poorly because of infection with toxigenic *C. diphtheriae* and 2) soldiers had to be immunized while deployed at the end of World War II once diphtheria became a major epidemic disease in Europe.

Few modern medical officers have any experience with what many now think to be extinct diseases, despite the perpetual presence of those pathogens in our environment. Tetanus is still a problem in unimmunized populations.[21] When public health systems failed to deliver universal toxoid immunization, diphtheria epidemics resulted, as seen in the former Soviet Union and Yemen.[7,8] When health systems collapsed in failed states such as Yemen and in conflict border areas of Pakistan, epidemic diphtheria resulted.[8,22]

Fear of adverse events and practical issues in screening soldiers for pre-existing immunity against other diseases exists today, but failure to continue current toxoid vaccination policies could once again threaten U.S. soldiers with preventable illnesses from ubiquitous environmental bacterial toxins. Force protection measures, specifically immunization, must be maintained if the U.S. Army is not to rediscover the effects of diseases such as tetanus and diphtheria.

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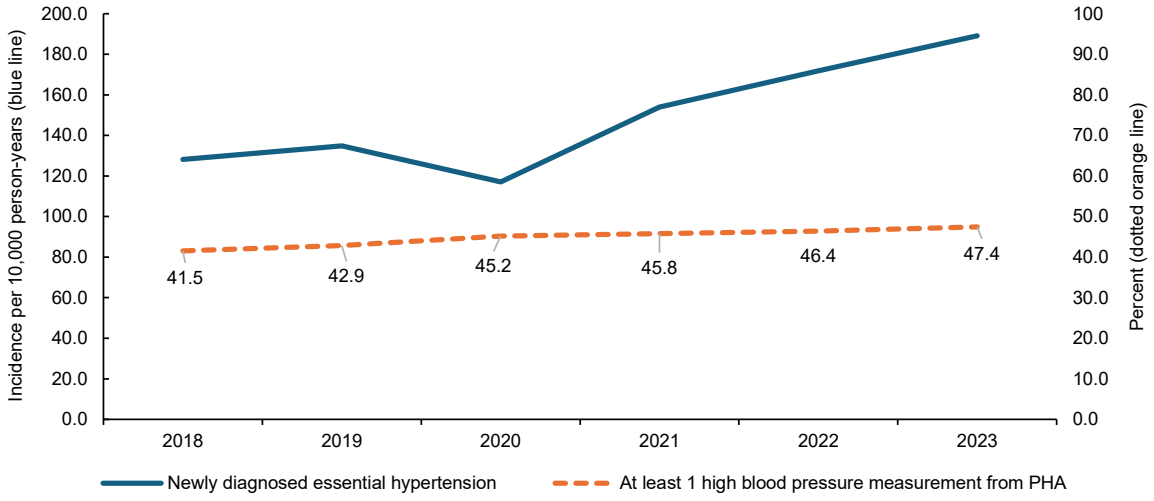
Surveillance Snapshot

Trends in Hypertension and Hypertensive Disease Among Active Component U.S. Service Members, 2018–2023

Shauna L. Stahlman, PhD, MPH; Lori M. Tantlinger, MD, MPH

FIGURE. Incidence of Essential Hypertension and Prevalence of High Blood Pressure Measurements[a], Active Component U.S. Service Members, 2018–2023



[a] High blood pressure measurement was defined by systolic blood pressure ≥130 mmHg or diastolic blood pressure ≥80 mmHg.

Hypertension, defined as persistent abnormal elevation of blood pressure above 130/80 mmHg, is estimated to have affected more than 47% of U.S. adults between 2021 and 2023.[1,2] Essential hypertension comprises the majority (95%) of hypertension cases and has no identifiable cause, while secondary hypertension stems from underlying medical conditions such as renal or endocrine disorders.[3,4] As a major risk factor for cardiovascular disease, hypertension can lead to heart and kidney damage if uncontrolled, which highlights the importance of early intervention on modifiable risk factors such as diet and exercise. This study aimed to examine the trend in annual incidence of hypertension and hypertensive disease, as well as the annual percentage of high blood pressure measurements, among active component service members between 2018 and 2023, using data from the Defense Medical Surveillance System (DMSS).

Incident cases of essential hypertension (International Classification of Diseases, 9th Revision [ICD-9] codes 401*; International Classification of Diseases, 10th Revision [ICD-10] codes I10*), secondary hypertension (ICD-9: 405*; ICD-10: I15*), and hypertensive crisis (ICD-10: I16*; no equivalent ICD-9 code) were identified by the presence of a single inpatient or outpatient encounter with a diagnosis listed in any diagnostic position. Hypertensive heart or kidney disease (ICD-9: 402*–404*; ICD-10: I11*–I13*) cases required documentation of an inpatient encounter or at least 2 outpatient encounters within 60 days of each other with the diagnosis listed in the first or second diagnostic position. Periodic Health Assessment (PHA) data were utilized to describe the annual percentages of service members who had 1 or more high blood pressure measurements, among those who had at least 1 recorded blood pressure measurement available. A high blood pressure measurement was defined by systolic blood pressure greater than or equal to (≥) 130 mmHg or diastolic blood pressure greater than or equal to (≥) 80 mmHg.

Incidence of diagnosed essential hypertension increased from 128.2 to 189.1 per 10,000 person-years (2018–2023), with a temporary decrease in 2020 likely related to reduced health care access during the COVID-19 pandemic **(Figure)**. The percentage of service members who had at least 1 recorded high blood pressure measurement increased from 41.5% to 47.4% during the same period, with the largest annual increase occurring between 2019 and 2020. Secondary hypertension decreased from 4.0 per 10,000 person-years (p-yrs) in 2018 to 2.3 per 10,000 p-yrs in 2023 **(Table)**. Hypertensive heart or kidney disease and hypertensive crisis remained stable (averaging 1.5 and 2.8 per 10,000 p-yrs, respectively).

TABLE. Incidence of Hypertension and Other Hypertensive Disease (per 10,000 person-years), Active Component U.S. Service Members, 2018–2023

	2018		2019		2020		2021		2022		2023	
	No.	Rate	No.	Rate	No.	Rate	No.	Rate	No.	Rate	No.	Rate
Essential hypertension	15,567	128.2	16,622	134.8	14,573	117.1	19,255	154.0	20,835	171.8	22,364	189.1
Secondary hypertension	517	4.0	504	3.8	441	3.3	480	3.6	348	2.7	295	2.3
Hypertensive crisis	306	2.4	353	2.7	329	2.5	400	3.0	374	2.9	402	3.2
Hypertensive heart or chronic kidney disease	175	1.4	202	1.5	185	1.4	211	1.6	194	1.5	223	1.8

Abbreviation: No., number.

The increase in essential hypertension among U.S. military personnel is consistent with recent increasing trends of risk factors including obesity and type 2 diabetes,[5] and suggests that military fitness requirements alone are insufficient to prevent the development of hypertension. Military members did not, however, show increased rates of more severe hypertensive conditions, possibly indicating protective factors within military health care or lifestyle. In 2017, the definition for high blood pressure was lowered from 140/90 mmHg to 130/80 mmHg, which raised concerns that increased diagnoses of essential hypertension could be attributed to previously undiagnosed individuals.[6] The consistent increase in elevated blood pressure measurements on PHAs suggests a real increase, however, not just more diagnoses occurring under the new guidelines.

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The views expressed in this Surveillance Snapshot are those of the authors and do not necessarily reflect official policy nor position of the Department of the Navy, Department of Defense, or the U.S. Government.

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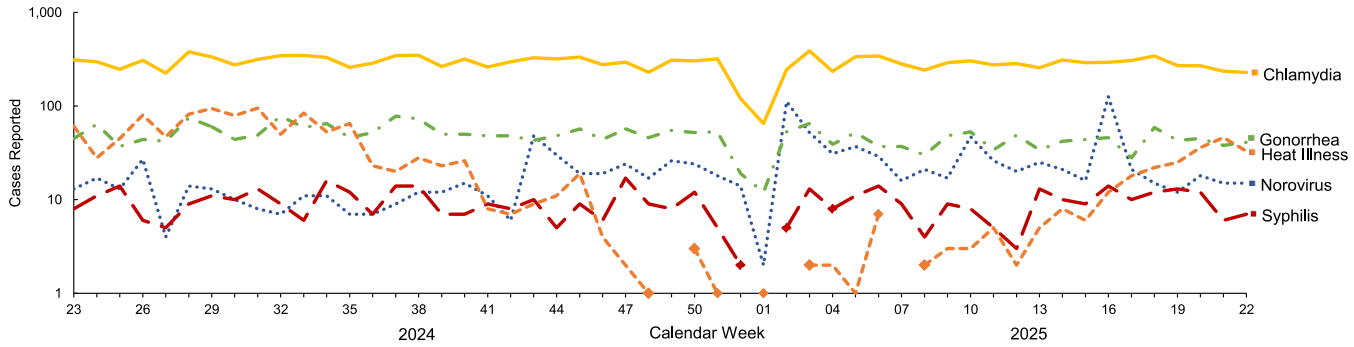
Reportable Medical Events at Military Health System Facilities Through Week 22, Ending May 31, 2025

Idalia Aguirre, MPH; Matthew W.R. Allman, MPH; Anthony R. Marquez, MPH; Katherine S. Kotas, MPH

TOP 5 REPORTABLE MEDICAL EVENTS[a] BY CALENDAR WEEK, ACTIVE COMPONENT (JUNE 8, 2024 - MAY 31, 2025)



Abbreviation: RMEs, reportable medical events.

[a]Cases are shown on a logarithmic scale.

Note: There were 0 reported heat illness cases during weeks 49, 52, 2, and 7. There were no syphilis cases reported during week 1 of 2025.

Reportable Medical Events (RMEs) are documented in the Disease Reporting System internet (DRSi) by health care providers and public health officials throughout the Military Health System (MHS) for monitoring, controlling, and preventing the occurrence and spread of diseases of public health interest or readiness importance. These reports are reviewed by each service's public health surveillance hub. The DRSi collects reports on over 70 different RMEs, including infectious and non-infectious conditions, outbreak reports, STI risk surveys, and tuberculosis contact investigation reports. A complete list of RMEs is available in the *2022 Armed Forces Reportable Medical Events Guidelines and Case Definitions*.[1] Data reported in these tables are considered provisional and do not represent conclusive evidence until case reports are fully validated.

Total active component cases reported per week are displayed for the top 5 RMEs for the previous year. Each month, the graph is updated with the top 5 RMEs, and is presented with the current month's (May 2025) top 5 RMEs, which may differ from previous months. COVID-19 is excluded from these graphs due to changes in reporting and case definition updates in 2023.

For questions about this report, please contact the Disease Epidemiology Branch at the Defense Centers for Public Health–Aberdeen. Email: dha.apg.pub-health-a.mbx.disease-epidemiologyprogram13@health.mil

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TABLE. Reportable Medical Events, Military Health System Facilities, May 2025[a]

Reportable Medical Event[b]	Active Component[c]					MHS Beneficiaries[d]
	May 2025	April 2025	YTD 2025	YTD 2024	Total 2024	May 2025
	No.	No.	No.	No.	No.	No.
Amebiasis	1	0	8	6	15	0
Arboviral diseases, neuroinvasive and non-neuroinvasive	0	0	0	0	4	0
Botulism	0	0	0	0	0	1
Brucellosis	0	0	0	0	1	0
COVID-19-associated hospitalization or death	1	2	18	19	41	12
Campylobacteriosis	24	30	115	108	326	19
Chikungunya virus disease	0	0	0	0	1	0
Chlamydia trachomatis infection	1,133	1,371	6,093	7,006	16,028	144
Cholera O1 or O139	0	0	0	1	3	0
Coccidioidomycosis	4	2	11	32	53	0
Cold weather injury[e]	16	25	271	133	174	N/A
Cryptosporidiosis	7	6	29	31	82	3
Cyclosporiasis	1	1	3	0	11	0
Dengue virus infection	1	1	5	5	12	0
E. Coli, Shiga toxin-producing	12	5	26	27	93	4
Ehrlichiosis and anaplasmosis	0	0	0	1	1	1
Giardiasis	10	9	41	39	98	3
Gonorrhea	195	183	929	1,219	2,819	29
H. influenzae, invasive	0	1	2	3	3	1
Heat illness[e]	149	55	239	224	1,276	N/A
Hepatitis A	0	0	0	4	7	0
Hepatitis B, acute and chronic[f]	7	7	32	51	108	5
Hepatitis C, acute and chronic	1	3	11	14	33	5
Influenza-associated hospitalization[g]	2	7	47	34	54	6
Lead poisoning, pediatric[h]	N/A	N/A	N/A	N/A	N/A	7
Legionellosis	0	0	0	3	5	1
Leprosy	0	0	0	0	1	0
Listeriosis	0	0	1	0	0	0
Lyme disease	10	4	23	35	101	11
Malaria	2	1	4	4	21	1
Meningococcal disease	1	0	1	0	2	0
Mpox	1	0	3	4	14	0
Mumps	0	0	1	0	0	1
Norovirus infection	66	184	694	179	654	70
Pertussis	5	4	24	9	39	5
Q fever	0	0	0	0	3	0
Rabies post-exposure prophylaxis	42	56	220	244	635	25
Salmonellosis	12	12	42	45	160	16
Schistosomiasis	0	0	0	0	1	0
Shigellosis	2	3	12	20	53	1
Spotted fever rickettsiosis	5	4	13	8	22	2
Syphilis[i]	46	45	195	284	563	11
Toxic shock syndrome	0	0	0	2	2	0
Trypanosomiasis	0	0	1	1	5	0
Tuberculosis	1	1	3	2	6	1
Tularemia	0	0	0	1	1	0
Typhoid fever	0	0	0	0	1	0
Typhus fever	0	0	1	1	2	0
Varicella	3	1	6	7	18	4
Zika virus infection	0	0	0	1	1	0
Total Case Counts	1,760	2,023	9,124	9,807	23,553	389

Abbreviations: MHS, Military Health System; YTD, year-to-date; No., number; COVID-19, coronavirus disease 2019; N/A, not applicable; *E., Escherichia*; *H., Haemophilus*; RME, reportable medical event.

[a] RMEs submitted to DRSi as of Jul. 18, 2025. RMEs were classified by date of diagnosis or, where unavailable, date of onset. Monthly comparisons are displayed for the period of Apr. 1, 2025–Apr. 30, 2025 and May 1, 2025–May 31, 2025. YTD comparison is displayed for the period Jan. 1, 2025–May. 31, 2025 for MHS facilities. Previous year counts are provided as the following: previous YTD, Jan. 1, 2024-May 31, 2024; total 2024, Jan. 1, 2024–Dec. 31, 2024.

[b] RME categories with 0 reported cases among active component service members and MHS beneficiaries for the time periods covered were not included in this report.

[c] Services included in this report include Army, Navy, Air Force, Marine Corps, Coast Guard, and Space Force, including personnel classified as Active Duty, Cadet, Midshipman, or Recruit in DRSi.

[d] Beneficiaries included individuals classified as Retired and Family Members (including Spouse, Child, Other, Unknown). National Guard, Reservists, civilians, contractors, and foreign nationals were excluded from these counts.

[e] Only reportable for service members.

[f] Observed decrease in hepatitis B cases from 2024 to 2025 may in part, be attributed to an updated case validation process.

[g] Influenza-associated hospitalization is reportable only for individuals under age 65 years.

[h] Pediatric lead poisoning is reportable only for children ages 6 years or younger.

[i] Observed drop in syphilis cases from 2024 to 2025 may be due, in part, to an updated case validation process that began Jan. 2024.

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