Unexpected outbreaks of arbovirus infections: lessons learned from the Pacific and tropical America

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Pandemic arboviruses have emerged as a major global health problem in the past four decades. Predicting where and when the next arbovirus epidemic will occur is a challenge, but history suggests that arboviral black swan events (epidemics that are difficult to predict and that have an extreme effect) will continue to occur as urban growth and globalisation expand. We briefly review unexpected arbovirus epidemics that have occurred in the past 50 years, with emphasis on the American and Pacific regions, to illustrate their unpredictability, and to highlight the need for improved global preparedness, including laboratory-based surveillance, prevention, and control programmes.

Lancet Infect Dis 2018; 18: e355–61

Published Online June 19, 2018 http://dx.doi.org/10.1016/S1473-3099(18)30269-X

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Introduction

The incidence of arthropod-borne viruses (arboviruses) has increased substantially during the past four decades. More than 500 viruses, belonging to the Flaviviridae, Togaviridae, Reoviridae and Bunyaviridae families, are registered in the International Catalogue of Arboviruses, and more than 100 are implicated in human disease. Predictions of the global spread of dengue virus were ignored as the disease spread into the Pacific, the Americas, and then globally.[1–5] As of 2018, dengue virus is endemic globally in the tropics and infects an estimated 400 million people annually.[6] Other arboviruses have circulated sporadically in most areas of the world.[5,7–11] However, the emergence of the epidemic and epizootic West Nile virus in the Americas (1999–2004) and the epidemics of chikungunya virus (2004–14) and Zika virus (2007–17) were truly black swan events (ie, epidemics that are difficult to predict and that have an extreme effect), which had substantial public health and economic effects that took the world by surprise.[10,12–17]

The expansion of areas affected by the West Nile virus, chikungunya virus, and Zika virus beyond Africa was preceded by waves of outbreaks that occurred in the Mediterranean Basin (West Nile virus) and islands of the Indian Ocean (chikungunya virus), Caribbean (chikungunya virus), and Pacific (Zika virus),[18] before the occurrence of large epidemics in the Americas. Epidemic Zika virus was also unexpectedly associated with severe neurological disease (Guillain-Barré syndrome) that was first reported in adults in French Polynesia,[19,20] followed by clusters of microcephaly in Brazil,[21] leading WHO to declare a Public Health Emergency of International Concern.[16] Thus, in a few short years, these arboviral diseases have moved from the status of neglected tropical diseases to global public health concerns, underscoring the need to prepare for the next arboviral emergence.

Given that the Pacific and tropical American regions had a determinant role in initiating and facilitating the expansion of arboviral diseases, we reviewed specific epidemics that occurred in the past five decades (table 1, 2), to illustrate the unpredictable nature of their emergence.

History of arboviruses in the Pacific region and tropical America

Dengue viruses

The first arbovirus to be reported in the Pacific islands was dengue virus at the end of the 19th century, which caused major epidemics during World War 2.[31] Since the 1960s, the Pacific region had regular dengue outbreaks, mostly caused by a single dengue virus serotype.[31] The Caribbean islands were a source of dengue virus introductions into the Pacific region (especially French Polynesia) throughout the 1990s, but subsequent viruses were mostly introduced from southeast Asia.[31,32] Generally, new dengue virus serotypes that caused an outbreak in one Pacific country subsequently spread to other Pacific countries, often replacing the circulating serotype.[32] Since 2000, the epidemiology has changed from hypoendemic (one serotype) to hyperendemic (multiple serotype co-circulation),[7] underscoring the increased movement of dengue virus serotypes, genotypes, and subtypes, and of other viruses (eg, chikungunya virus and Zika virus) into and around the Pacific Basin, primarily through human traffic from all parts of the world.[54]

Outbreaks of dengue fever-like disease were common in the Americas in the 19th century, but disappeared in the mid-20th century with implementation of the Pan American Health Organization regional *Aedes aegypti* eradication programme, which eliminated the mosquito from 23 American countries.[1,2] This highly successful programme was disbanded in the early 1970s because of its high cost and because epidemic yellow fever and dengue fever had been effectively controlled.[1,48] Over the next 30 years, *A aegypti* reinfested most of those countries, facilitated by the unprecedented urbanisation of the region and the deterioration of mosquito control programmes.[2,48] The result has been a substantial increase in the frequency and magnitude of epidemic dengue in tropical America.[1–5,31,48,54] Even though *A aegypti* is present in much of Brazil,[45] we do not know why only small outbreaks have occurred in São Paulo, whereas large outbreaks have occurred in Santos, located 60 km away.[55] Additionally, several dengue fever outbreaks occurred in Rio de Janeiro, Brazil.[56] In Argentina, local transmission of dengue virus was first reported in 2009, with 26 000 infections notified, although in Buenos Aires

	Main mosquito vectors	First description of the virus (year and country)	First disease description (year and country)	Past outbreaks and ongoing circulation
Alphavirus genus				
Ross River[22-25]	*Aedes vigilax; Aedes camptorhynchus; Aedes notoscriptus; Culex annulirostris; Aedes polynesiensis*	1959 in mosquitoes (Australia) and 1972 in humans (Australia)	Epidemic polyarthritis in 1928 (Australia)*; first confirmed human infection in 1972 (Australia); first human-mosquito-human transmission in 1980 (Cook Islands)	Northern Australia and Papua New Guinea during World War 2; Australia in 1956; Pacific islands in 1979–80; ongoing circulation in Australia and Papua New Guinea†; silent circulation in French Polynesia, American Samoa, and Fiji‡
Chikungunya[13,26-28]	*Aedes aegypti; Aedes polynesiensis* (Polynesian islands)	1952 (Tanzania)	2011 (New Caledonia)	Spread in the Pacific from 2011 to 2015 (American Samoa, Cook Islands, Federated States of Micronesia, French Polynesia, New Caledonia, Papua New Guinea, Samoa, Tokelau, and Tonga)
Barmah forest[9]	*Aedes notoscriptus; Aedes vigilax; Aedes procax*	1974 in mosquitoes (Australia) and 1986 in humans (Australia)	1986 (Australia)	Australia since 1992 (1000–4000 infection cases annually)
Flavivirus genus				
Zika[15-18,29,30]	*Aedes aegypti; Aedes hensilli* (Yap Islands); *Aedes polynesiensis*	1947 in a sentinel rhesus monkey (Uganda)	2007 (Yap Islands and Federated States of Micronesia)	Yap Island in 2007; French Polynesia in 2013–14; circulation reported in 13 Pacific countries and territories from 2013 to 2017 (American Samoa, Cook Islands, Federated States of Micronesia, French Polynesia, Fiji, Marshall Islands, New Caledonia, Papua New Guinea, Palau, Samoa, Solomon Islands, Tonga, and Vanuatu)
Dengue[7,31-34]	*Aedes aegypti; Aedes polynesiensis; Aedes hensilli*	1944 (Japan)	End of 19th century	Widely distributed; endemic and epidemic circulation
Murray Valley encephalitis[9,35]	*Culex annulirostris*	1951 in humans (Australia)	1951 (Australia)	Australia in the early 20th century, and in 1951, 1974, 2000, and 2011§; low ongoing circulation in Australia and Papua New Guinea†
Kunjin (subtype of West Nile virus)[36,37]	*Culex annulirostris;* other *Culex* spp	1960 in mosquitoes (Australia)	1986 (Australia)	Australia (equine outbreak) in 2011 and sporadic human infections in northern Australia
Japanese encephalitis[9,33,38]	*Culex annulirostris; Culex tritaeniorhynchus; Culex sitiens*	1935 (Japan)	1995 (Australia)	Guam, in 1947; Northern Mariana Islands, in 1990; sporadic cases since 1990 in Northern Australia and in Papua New Guinea§

*Outbreaks probably caused by Ross River virus. †Probable circulation in Papua New Guinea but no recently confirmed cases. ‡According to serosurvey studies in French Polynesia and American Samoa. §Possible causative agent of encephalitis in the early 20th century in Australia, reported as Australian disease.

Table 1: **Principal endemic arboviruses in the Pacific region**

only 100 cases were reported, despite the presence of *A aegypti* in this urban centre.[57]

Chikungunya virus

Chikungunya virus caused major epidemics in Asia from the 1950s to the 1980s, and then disappeared. When the East-Central South African (ECSA) virus lineage re-emerged in the East African Islands in 2004, it gave rise to a new lineage, the Indian Ocean lineage (IOL).[10] Chikungunya virus, as expected, was reintroduced to Asia, causing a major epidemic in India in 2006, which then spread throughout southeast Asia (chikungunya virus of Asian lineage).[10] Chikungunya virus was first detected in the Pacific in 2011 in New Caledonia, and subsequently spread throughout the south and central Pacific.[13,26] Surprisingly however, the virus belonged to the Asian lineage,[13–21,26,31,32,48,54–57] not to the ECSA or IOL lineages that emerged in the East African Islands. The strain isolated in Papua New Guinea (west Pacific) belonged to the ECSA lineage,[26] and another isolated in French Polynesia in late 2014 belonged to the Asian lineage, apparently introduced from Guadeloupe, in the Caribbean.[27]

The chikungunya virus was first detected in the Americas in Saint Martin in the Caribbean, in December, 2013. The virus belonged to the Asian lineage and was probably introduced from the Pacific region.[58] From the Caribbean, the chikungunya virus subsequently spread to several continental American countries, including Brazil. In 2014, the ECSA chikungunya virus lineage also appeared in Brazil, probably introduced by a returning traveller from Angola.[58] The chikungunya virus IOL lineage that caused large outbreaks in the Indian Ocean and parts of Asia did not emerge in the Americas despite many cases having been imported.[10]

How and why three chikungunya virus lineages suddenly caused major outbreaks during the same decade after several decades of silent transmission remains uncertain. We can only speculate that high herd immunity was sufficient to prevent new outbreaks in previously affected areas.

Zika virus

Zika virus has been widespread in Africa and Asia for decades, but epidemics were unknown until 2007 when,

	Main mosquito vectors	First description of the virus (year and country)	First disease description (year and country)	Past outbreaks and ongoing circulation
Alphavirus genus				
Mayaro[8,14,39,40]	*Haemagogus* spp	1954 (Trinidad and Tobago)	1954 (Trinidad and Tobago)	Past outbreaks and ongoing circulation in South America and the Caribbean
Chikungunya[8,10,14]	*Aedes aegypti*	1952 (Tanzania)	2013 (Saint Martin in the Caribbean)	Possible outbreaks in the 18th and 19th centuries; spread in the Americas from 2013; still circulating in 2017*
Venezuelan equine encephalitis[8,41]	*Culex* spp (enzootic cycle); *Ochlerotatus; Pseudophora* spp (epizootic cycle)	1938 in horses (Venezuela)	1920s (Venezuela) and isolated in human beings in 1967 (Colombia)	Several outbreaks (in humans and horses) since 1938 in South and Central America, Mexico, and southern USA; last outbreak (75 000–100 000 human cases) in 1995 in Venezuela and Colombia
Eastern equine encephalitis[8,42]	*Culex pedroi* (enzootic cycle); *Aedes taeniorhynchus* (epizootic cycle)	1938 in humans (USA)	1972 in humans (Trinidad and Tobago)†	Sporadic equine and human encephalitis in North America, a small outbreak in Panama in 2010, and only three reported cases in Latin America (Trinidad and Tobago and Brazil)
Western equine encephalitis[43]	*Aedes* spp; *Culex* spp	1930 in horses (USA)	1941 (Canada and USA)	Widespread outbreaks of equine epizootics and encephalitis epidemics in western and North America from the 1930s to the 1950s; epizootic outbreaks in 1972–73 and 1982–83 in Argentina; and sporadic cases in South America (Uruguay in 2009)
Flavivirus genus				
Zika[16,17,44]	*Aedes aegypti*	1947 in a sentinel rhesus monkey (Uganda)	2015 (Brazil)‡	Spread in the Americas from 2015; circulation decreasing in 2017†
Yellow fever[8,45–47]	*Haemagogus* spp; *Sabethes Aedes aegypti*	1927 (Ghana)	1648 (Mexico)	13 American countries are considered endemic by WHO;§ ongoing circulation in Brazil in 2016–17
Dengue[5,48]	*Aedes aegypti; Aedes albopictus*	1944 (Japan)	1635 (Caribbean)	Most common arbovirus in Latin America (0·9–2·4 million cases annually in the past decade)*
Rocio[8,49,50]	*Psorophora ferox*	1975 (Brazil)	1975 (Brazil)	Only one outbreak in Brazil in 1973–80 (about 1000 cases)
Saint Louis encephalitis[8,49,50]	*Culex declarator; Culex coronator*	1933 (USA)	1960 in mosquitoes (Brazil)	Ongoing circulation in the Americas from Canada to Argentina
***Orthobunyavirus* genus**				
Oropuche[8,51]	*Aedes serratus; Culex quinquefasciatus; Culicoides paraensis*	1955 in humans (Trinidad and Tobago)	1955 in humans (Trinidad and Tobago)	30 major outbreaks since the first isolation of the virus in tropical America; subsequent outbreaks in Latin America (≤100 000 cases); the Oropuche virus is the second most common arbovirus in Brazil

*Pan American Health Organization website.[52] †Epizootic outbreak reported in 1973 in Latin America. ‡Outbreak of exanthematous illness reported in late 2014. §WHO website.[53]

Table 2: **Principal endemic arboviruses in tropical America.**

unexpectedly, an outbreak occurred in the Yap Islands in the western Pacific.[15] Zika virus was not reported again in the region until 2013, when a second outbreak occurred in French Polynesia in the eastern Pacific.[59] During this outbreak, the causal link between Zika virus infection and severe neurological complications in adults was identified, and the potential for post-transfusion, maternofetal, and sexual transmission of Zika virus was described.[17,19,20] Zika virus then spread rapidly through the Pacific region and subsequently to the Americas.[17,41] This emergence of the virus in these regions was associated with the description of the congenital Zika syndrome, which had never before been reported with other arboviruses.[16,17] Zika virus caused only a few small outbreaks in southeast Asia (Singapore, Vietnam, and Thailand),[60] despite similarly favourable conditions. The origins of the Zika viruses introduced to the Yap Islands and French Polynesia are unknown, although the French Polynesian virus was phylo-genetically closer to a strain isolated in Cambodia in 2010 than to the virus that caused the Yap Islands outbreak.[59] The virus that caused the American epidemics was of the Asian lineage.[61] The only known Zika virus outbreak in Africa was also caused by a virus of the Asian lineage, which was probably introduced from Brazil.[60,61] As with the dengue virus in Brazil, few Zika virus infection cases were reported in São Paulo city, whereas Santos and neighbouring cities had a high number of cases.

West Nile virus

In 1999, a true arboviral black swan event occurred when the West Nile virus emerged in New York City, NY, USA, causing an unprecedented epizootic epidemic in birds, horses, and humans, which rapidly spread throughout North America over the next years and subsequently became enzootic with annual outbreaks.[12,62–64] Although how and when the virus was introduced remains uncertain, a retrospective review of epidemiological data suggests that a new strain of West Nile virus that had greater epidemic potential and virulence emerged in the Mediterranean region in the mid-1990s, causing several major and minor outbreaks that were not recognised as important.[62] This virus strain was then introduced to the western hemisphere.[64]

The absence of major West Nile virus epizootics or epidemics in Central and South America despite the presence of the virus in animals, is puzzling.[63,65,66] Numerous other flaviviruses circulate in that region, some of which cause neurological disease in humans and horses. Serological crossreactivity among flaviviruses combined with low laboratory-based surveillance make it difficult to distinguish West Nile virus infection from infections caused by other flaviviruses. Even so, an outbreak of neurological disease in horses or humans would probably be recognised. We can only speculate that crossprotective flavivirus antibody downregulated clinical disease, that the virus mutated again to a less virulent strain (as previously reported for dengue virus),[67] that the predominant mosquito vectors in Central and South America are less competent than the species in North America (*Culex pipens, Culex quinquefasciatus,* and *Culex tarsalis*), or that a combination of all these factors has prevented epidemics and epizootics in the southern hemisphere.[62,63,68] So far, only one isolated West Nile virus human infection has been reported in South America (Brazil),[69] but the occurrence of other isolated and undetected West Nile virus human infections in Latin America cannot be excluded.

The West Nile virus strain that emerged in the western hemisphere was never detected in the Pacific region. However, a subtype of West Nile virus known as Kunjin virus is endemic in Australia, and causes sporadic human infections.[36] A new Kunjin virus strain emerged in 2011 in Australia causing a large outbreak in horses, but was not associated with higher virulence in humans.[37]

Yellow fever virus

Epidemic urban yellow fever was effectively controlled in west Africa and the Americas in the 1940s and 1950s with vaccines and *A aegypti* control.[5] However, increasing urban growth, infestation of tropical cities by *A aegypti* (the principal urban vector of the yellow fever virus), and globalisation have substantially increased the risk of urban yellow fever in recent years.[4,5,70,71] Since *A aegypti* is widely distributed in Pacific and Asian cities, yellow fever is predicted to be introduced to the region at some point, possibly causing a global public health emergency.[4,5,11]

The history of dengue virus, chikungunya virus, Zika virus, and West Nile virus vividly shows the ease of movement of mosquito transmitted viruses among the African, Asian, Pacific, and American regions, suggesting that if urban transmission of yellow fever virus begins, it will be introduced into the Asia–Pacific region. The yellow fever virus epidemics in Angola, Democratic Republic of the Congo, and Brazil underscored this fact, as did confirmation that yellow fever virus had been introduced to Asia (China) for the first time in history.[72] Fortunately, the viruses were introduced during the cold months of the year and in areas where *Aedes* spp mosquitoes are in small numbers. Why urban epidemic yellow fever virus has not emerged in Latin America where most urban centres have been reinfested with *A aegypti* remains perplexing.[5] This question is especially pertinent on the Atlantic coast of Brazil, where the population is dense and most people are not vaccinated for yellow fever virus.[45] Brazil had a major yellow fever virus epidemic in 2016–17 that continues today, involving both humans and non-human primates.[46] The epidemic began in the inland state of Minas Gerais and moved to the coastal states of Espírito Santo, Rio de Janeiro, and São Paulo, the most densely populated areas of Brazil that also harbour the lowest yellow fever virus vaccination coverage. The epidemic intensified in São Paulo and Rio de Janeiro in 2018. However, to date human cases have been reported only as sylvatic, even though the urban centres where cases have occurred are infested with *A aegypti*.[47] Worryingly, green parks inside the urban area of São Paulo were closed to the public in November, 2017, as a result of macaque deaths with laboratory confirmation of yellow fever virus infection. *Aedes albopictus,* which is widely distributed in Brazil, is a laboratory-competent vector for yellow fever virus that could act as a bridge vector,[45] but historically the mosquito has not been associated with large epidemics (except dengue virus and chikungunya virus epidemics in other parts of the world).

Pacific arboviruses with epidemic potential

Epidemic polyarthritis caused by Ross River virus unexpectedly emerged in the Pacific in 1979–80, involving Fiji, New Caledonia, Wallis and Futuna, Samoa, and the Cook Islands.[22,23] Ross River virus is the most common arbovirus in Australia causing an estimated 5000 human infections annually, with an increased number of cases in 2017 in New South Wales, Australia, and Papua New Guinea.[22,23] No Ross River virus outbreaks have been reported in the Pacific since 1980, despite a probable silent circulation of the virus in French Polynesia, American Samoa, and Fiji.[73]

The Barmah Forest virus, an alphavirus, is the second most common arbovirus in Australia with up to 4000 infection cases reported annually; however, the virus has never been reported outside Australia.[9] The Murray Valley encephalitis virus caused a small number of human infections in Australia and Papua New Guinea.[9,35] Intriguingly, the Ross River virus, Kunjin virus, Barmah Forest virus, and Murray Valley encephalitis virus have never been detected in southeast Asia despite the presence of competent vectors.

The Japanese encephalitis virus is highly endemic in southeast Asia (with an estimated 50 000 infection cases and 15 000 deaths annually) and is transmitted by *Culex* spp mosquitoes.[38] The virus has caused only small outbreaks in the Pacific (Guam, and Northern Marianna Islands) and caused sporadic infections in north Australia and Papua New Guinea,[9,38] despite the wide distribution of competent mosquito vectors in the Pacific region.[33]

American arboviruses with epidemic potential

Several arboviruses in the American region have not caused outbreaks outside their endemic areas. These include the Mayaro virus,[8,14,39,40] Venezuelan equine encephalitis virus,[8,41] Oropouche virus,[8,51] and Rocio virus.[8,49,50]

The Mayaro virus and Venezuelan equine encephalitis virus, belonging to the Alphavirus genus, and the Oropouche virus, belonging to the Orthobunyavirus genus, have the greatest potential for geographical spread on a larger scale, because all these viruses are widespread in tropical America, cause epidemics, can be transported by viraemic humans, and can be transmitted by *A aegypti*.[14,39,41,51] During the last major Venezuelan equine encephalitis virus epidemic in Venezuela and Colombia in 1995, an estimated 75 000–100 000 humans were infected (causing 3000 encephalitis cases) and 50 000 equine cases were reported.[41]

The Rocio virus, a Flavivirus, is transmitted by *Aedes* spp and *Psorophora* spp mosquitoes, and in the 1970s caused an outbreak in the state of São Paulo, Brazil, leading to more than 1000 human encephalitis cases with a mortality rate of 10%.[8,49] Sporadic transmission continued for 7 years and then disappeared, with no human outbreaks subsequently recorded. A few encephalitis and asymptomatic seropositive human cases were identified in northeast Brazil in 1995, and in north Brazil in 2010.[49] Serosurveys on humans and horses suggest that the Rocio virus is enzootic in Brazil and possibly in other South American countries.[49,50]

Unpredictability of the emergence and re-emergence of arboviruses

The epidemiology of arboviruses is complex, involving many intrinsic and extrinsic variables, such as transmission by multiple vectors, amplification in multiple vertebrate hosts, and variable temperature, rainfall, vegetation patterns, and humidity. Humans are dead-end hosts for most arboviruses, because viraemia is too low to allow the subsequent infection of an arthropod vector; notable exceptions include the dengue virus, yellow fever virus, Zika virus, chikungunya virus, Mayaro virus, Ross River virus, Barmah Forest virus, Oropouche virus, Venezuelan equine encephalitis virus, and other viruses that are as yet unknown. These viruses pose the greatest threat for epidemic transmission. Arboviruses have the ability to jump between species and adapt to new vectors and vertebrate hosts via mutations, which can increase virulence and epidemic potential. Adding to this complexity are, among other factors, globalisation (increased movement of humans, animals, commodities, and pathogens), natural and anthropogenic environmental changes (climate, land use, animal husbandry), demographic changes (population growth and urbanisation), and a shift from a sylvatic to suburban–urban cycle (and vice versa),[11,17,74] all of which increase the risk and unpredictability of epidemic arbovirus diseases.[4,11,75] The issue of herd immunity in arbovirus epidemiology is unclear, as exemplified by the history of Zika virus. In French Polynesia, Zika virus stopped circulating after more than half of the population had been infected, whereas in Latin America Zika virus circulation declined when less than 1% of the population was infected.[74]

Preparation for unpredictable emergence

The best examples of black swan arbovirus emergences are West Nile virus in the Americas and Zika virus globally, both occurring decades after their discovery in Africa and after decades of being ignored by the public health community. Public health institutions were not prepared for the spread of either virus, despite the previous global spread of epidemic dengue. Nevertheless, serological and molecular diagnostic tests and surveillance programmes were rapidly developed for both viruses, initially by the Centers for Disease Control and Prevention in the USA (both for West Nile virus and Zika virus) and by the Institut Louis Malardé in French Polynesia (for Zika virus).[20,59,76] These tests or adaptations of these tests were adopted by the international community, allowing for rapid response, description of clinical complications, the discovery of non-vector-borne transmission of Zika virus, and declaration of a public health emergency by the Brazilian Ministry of Health and WHO.[16] The lesson learned from these experiences is that more active laboratory-based surveillance should be developed and implemented in all areas where new diseases are likely to emerge, and in areas that are likely to be affected by rapidly spreading pathogens.[4,54,77] Areas where new diseases are likely to emerge include resource-poor countries that do not have adequate laboratory capacity, and where infectious disease surveillance is generally poor.[77] International organisations, particularly WHO, have a determinant role to play to strengthen the capacities of middle-income and low-income countries to face future virus emergences. The solution to this problem will require building laboratory and epidemiological capacity in these countries, and developing regional reference laboratories to support regional laboratory-based surveillance. This strategy will also allow the detection of other emerging pathogens because the unpredictability of infectious diseases is not limited to arboviruses.[78]

Conclusion

When Zika virus was first reported in the Americas, it was predicted to have the potential to follow in the path of dengue virus and chikungunya virus, although the magnitude of the epidemic and the substantial complications associated with Zika virus could not be known.[79] The concern is that other arboviruses have potential to emerge or re-emerge on a similarly large scale because of the demographic, societal, and environmental global trends of the 21st century.[4] Arboviruses that produce high viraemia in humans and domestic animals, and those that can be transmitted by

Search strategy and selection criteria

References were identified through PubMed searches (applying a restriction to English, Spanish, and Portuguese articles) using keywords "arbovirus", "alphavirus", "flavivirus", "Pacific", "America", "Zika", "dengue", "chikungunya", "yellow fever", "West Nile", and "emergence", from 1960 up until December, 2017. Multiple spellings, truncated nomenclatures, and abbreviations were also used in the search. Articles resulting from these searches and the most relevant references cited in those articles were reviewed.

domestic and peridomestic mosquitoes, have the greatest probability of causing pandemics.[71] High on the list of potential emergent arboviruses are well known viruses such as yellow fever virus, Mayaro virus, Ross River virus, Barmah Forest virus, Oropouche virus, Venezuelan equine encephalitis virus, and Rift Valley fever virus, as well as lesser known viruses such as Sepik virus, Spondweni virus, Kedougou virus, Edge Hill virus, Wesselsbron virus, Usutu virus, and o'nyong nyong virus. The unpredictability of the emergence of any of these viruses underscores the need for improving laboratory and surveillance capacity, and reinforces the need for global preparation for the worst-case scenario. This unpredictability also underscores the need for more research to better understand the ecology of these viruses, and to develop more effective prevention and control tools, including vaccines, drugs, and mosquito control.

Contributors
All authors contributed to the literature search and editing of this manuscript.

Declaration of interests
We declare no competing interests.

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