Abstract

The objective of this study is to characterize the seroprevalence of anti-dengue (DENV) and anti-chikungunya (CHIKV) antibodies among blood donors residing in Qatar who are Middle East and North Africa (MENA) nationals and non-nationals. Sera were collected from adult blood donors in Qatar from 2013 to 2016 and tested for anti-DENV and anti-CHIKV IgG using commercial microplate enzyme-linked immunosorbent assays. Age-specific seroprevalence was summarized by region/nationality: Asia (India, Philippines), Middle East (Iran, Jordan, Lebanon, Pakistan, Palestine, Syria, Yemen), North Africa (Egypt, Sudan), Qatar. The adjusted odds of anti-DENV and anti-CHIKV IgG seropositivity was estimated by logistic regression. Among 1,992 serum samples tested, Asian nationals had higher adjusted odds of being seropositive for anti-DENV antibodies compared to nationals of the Middle East (aOR 0.05, 95% CI 0.04–0.07), North Africa (aOR 0.14, 95% CI 0.10–0.20), and Qatar (aOR 0.01, 95% CI 0.01–0.03). Asian nationals also had higher adjusted odds of being seropositive for anti-CHIKV antibodies compared to those from the Middle East (aOR 0.14, 95% CI 0.07–0.27), North Africa (aOR 0.50, 95% CI 0.26–0.96), and Qatar (aOR 0.38, 95% CI 0.15–0.96). The adjusted odds of being anti-DENV seropositive was higher among anti-CHIKV seropositive adults, and vice versa (aOR 1.94, 95% CI 1.09–3.44), suggesting co-circulation of these viruses. DENV and CHIKV exposure is lower in Qatar and MENA nationals compared to Asian nationals suggesting a lower burden of DENV and CHIKV disease in the MENA. Antibodies to both viruses were detected in nationals from most MENA countries, supporting the need to better understand the regional epidemiology of these viruses.
Introduction

Although dengue (DENV) and chikungunya (CHIKV) viruses rank among the most important causes of arboviral diseases in the world, their epidemiology in the Middle East and North Africa (MENA) is sparsely characterized [1, 2]. Recent outbreaks of DENV and CHIKV have been documented in several MENA countries including Pakistan, Sudan, and Yemen, while in over half of MENA countries, no seroprevalence data has ever been published [1–8]. In Qatar, neither local transmission of DENV or CHIKV, nor the presence of their principal vectors, *Aedes aegypti* and *Aedes albopictus*, has yet been reported to our knowledge. However, the expansion of DENV in neighboring Saudi Arabia and Yemen underscores the importance of understanding the epidemiology of these pathogens and their potential for spread in Qatar and the surrounding region.

Qatar is situated on the northeastern coast of the Arabian Peninsula, surrounded by the Arabian Gulf and bordering Saudi Arabia to the south (Fig 1). Rainfall is infrequent (<100 mm annually) and average high temperatures often exceed 38˚C [9]. Modeling studies have identified low probability of occurrence of *Ae. aegypti* in Qatar on account of poor environmental suitability (e.g. high temperature, low precipitation), but potential for *Ae. albopictus* occurrence in urban areas of Qatar [10]. Still, Qatar has various characteristics that could influence the potential for local DENV and CHIKV transmission and present a unique opportunity to study the seroepidemiology of these viruses in the MENA. First, 88% of the country’s 2.2 million people are migrants from other countries [11]. Up to 60% of these migrants come from the Indian subcontinent and the Philippines, posing risk of imported infections from some of the most highly DENV and CHIKV endemic countries in the world [12–14]. Second, MENA nationals from Egypt, Pakistan, Syria, Sudan, Jordan, Iran, and Lebanon are estimated to make up approximately 22% of the country’s population [15]. In most of these countries, local DENV or CHIKV transmission, serologic evidence of past infection, or the presence of *Ae. aegypti* or *Ae. albopictus* has been documented, yet published epidemiologic data is lacking.

Blood donor serosurveys can be an efficient means of gaining preliminary insight into the epidemiology and potential burden of these viruses in this circumstance. Few blood donor

![Fig 1. Represented countries (n = 12) among Qatari nationals and immigrants residing in Qatar who were included in the study.](https://doi.org/10.1371/journal.pone.0211574.g001)
surveys have ever been conducted for DENV and CHIKV in the MENA region, and none have sampled nationals from other countries or compared prevalence to non-MENA nationals [16–22]. The objective of this study is to characterize the seroprevalence of anti-DENV and anti-CHIKV antibodies among blood donors residing in Qatar who are MENA and non-MENA nationals. Such data will address knowledge gaps in our understanding of the seroepidemiology of these pathogens in the MENA region, and their potential risk of emergence in Qatar.

**Methods**

**Ethics statement**

The research work was approved by the ethics boards and research committees at Qatar University, Hamad Medical Corporation, and Weill Cornell Medicine-Qatar. The requirement for informed consent was waived by these institutions given that samples were already de-identified at the time they were received for this research. All experiments were performed in accordance with relevant guidelines and regulations.

**Study design and participants**

This was a retrospective, cross-sectional study using de-identified blood samples collected from volunteer blood donors attending Hamad Medical Corporation in Qatar, the largest healthcare provider in the country, from June 2013 to June 2016. In total, 5,973 blood donors consented to submit blood specimens and basic demographic information (age, nationality, gender) which were analyzed in other studies [23–28]. A subset of this biobank, selected at random, was analyzed for this study. The original sample set included male and female Qatari and expatriates (MENA and non-MENA nationals) who were ≥18 years of age and residing in Qatar. In total, there were 5,799 men and 152 women, with gender type missing in 0.4% (n = 22) of participants, which served as the original sampling cohort for selection of the final sample. Given the low number of available samples from women, only samples from men were included in our study.

Sample sizes were calculated for a significance level of $\alpha = 0.05$. A minimum sample size of 100 was estimated for each country based on a projected overall anti-DENV antibody seroprevalence of 25% with 9% precision and an anti-CHIKV antibody prevalence of 1% with 2% precision [1, 2]. However, up to 200 samples were analyzed per country based on sample availability in order to increase the precision of the estimates. Attrition did not need to be accounted for, as it is minimal, given that a sufficient quantity of blood donor samples was known to be available from our prior studies of the seroprevalence of herpes simplex viruses [27, 28].

**Biological sample collection and laboratory analysis**

A total of 20 µL of serum was aliquoted from each participant’s sample that had been stored at -80°C. Sera were tested for the presence of anti-DENV and anti-CHIKV IgG (10 µL serum for each test) using commercial microplate enzyme linked immunosorbent assay (ELISA) kits for anti-DENV (NovaTec Immundiagnostica GmbH, Frankfurt, Germany, DENG0120) and anti-CHIKV (Euroimmun, Lübeck, Germany, EI 293a-9601 G) antibodies [29, 30]. These kits are designed for monospecific determination of IgG antibodies with 3-point quantitative calibration and approved by the United States Food and Drug Administration. As per the manufacturer, the anti-DENV IgG ELISA is based on purified virus particles of serotype 2, allowing for detection of virus serotypes 1–4 based on the structural similarities between them [31]. The sensitivity and specificity was 100% and 97%, respectively, in clinically characterized sera,
though cross-reactions with other flaviviruses can occur [20]. The anti-CHIKV ELISA uses a virus-specific structural protein as the antigenic substrate with a sensitivity and specificity of 95% and 88%, respectively [32]. Cross-reactions against o'nyong-nyong virus and Mayaro virus were observed in this latter study [32].

Data analysis

For each virus, the proportion of positive samples was summarized with 95% confidence intervals (CI) according to nationality and age across seven bands: ≤ 24, 25–29, 30–34, 35–39, 40–44, 45–49, and ≥ 50 years. Age-specific seroprevalence for each virus was also cross-tabulated by region: Asia (India, Philippines), Middle East (Iran, Jordan, Lebanon, Pakistan, Palestine, Syria, Yemen), North Africa (Egypt, Sudan), and Qatar. Regions were defined according to the MENA definitions of the World Health Organization Regional Office for the Eastern Mediterranean (WHO/EMRO), the Joint United Nations Programme on HIV/AIDS (UNAIDS), and the World Bank, and for consistency with our earlier dengue, chikungunya, and HIV regional publications [1, 2, 33–36]. Associations between nationality, age and seropositivity were summarized with odds ratios (ORs) and 95% CIs. Logistic regression was used to estimate the adjusted effects of age and regional nationality on the odds of seropositivity for anti-DENV and anti-CHIKV IgG separately, as well as the odds of anti-DENV IgG positivity in the setting of anti-CHIKV IgG positivity, and vice versa. Significance level was defined at α = 0.05. Data was analyzed using the Statistical Package for the Social Sciences (SPSS) version 24.

Results

A total of 1,992 serum samples from male subjects ≥ 18 years of age from 12 countries were tested for anti-DENV and anti-CHIKV IgG antibodies (Fig 1 and Table 1). The number of samples tested per country ranged from 97 (<100 due to insufficient serum) to 200. The median [IQR] age of subjects was 36 [30–43] years. Anti-DENV IgG was detected in six or more samples from individuals from every country, while anti-CHIKV IgG was detected in at least one sample from individuals from every country except Iran. The country-specific overall seroprevalence for anti-DENV IgG ranged from 3.5% (95% CI 1.6–6.8%) in Qatar to 95.8% (95% CI 91.0–98.4%) in the Philippines. For anti-CHIKV IgG, overall seroprevalence ranged from 0% in Iran to 17.7% (95% CI 11.6–25.2%) in the Philippines.

Table 1. Country-specific seroprevalence for anti-DENV IgG and anti-CHIKV IgG among subjects residing in Qatar but from different countries, from June 2013 to June 2016.

| Country     | Sample size | Anti-DENV IgG positive | % (95% CI) | Anti-CHIKV IgG positive | % (95% CI) |
|-------------|-------------|------------------------|------------|-------------------------|------------|
| Egypt       | 199         | 40                     | 20.1 (15.0–26.1) | 11                      | 5.5 (3.0–9.4) |
| India       | 200         | 125                    | 62.5 (55.7–70.0) | 22                      | 11.0 (7.2–15.9) |
| Iran        | 113         | 6                      | 5.3 (2.3–10.6)   | 0                       | 0 (0)      |
| Jordan      | 199         | 9                      | 4.5 (2.3–8.1)    | 1                       | 0.5 (0.1–2.3) |
| Lebanon     | 116         | 6                      | 5.2 (2.2–10.4)   | 1                       | 0.9 (0.1–4.0) |
| Pakistan    | 200         | 40                     | 20.0 (14.9–26.0) | 3                       | 1.5 (0.3–4.3) |
| Palestine   | 200         | 17                     | 8.5 (5.2–13.0)   | 6                       | 3.0 (1.2–6.1) |
| Philippines | 119         | 114                    | 95.8 (91.0–98.4) | 21                      | 17.7 (11.6–25.2) |
| Qatar       | 200         | 7                      | 3.5 (1.6–6.8)    | 7                       | 3.5 (1.6–6.8) |
| Sudan       | 97          | 47                     | 48.5 (38.7–58.3) | 5                       | 5.2 (2.0–10.9) |
| Syria       | 200         | 26                     | 13.0 (8.9–18.2)  | 1                       | 0.5 (0.1–2.3) |
| Yemen       | 149         | 36                     | 24.2 (17.8–31.5) | 4                       | 2.7 (0.9–6.3) |

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The overall and age-specific seroprevalence for each virus was also estimated for nationals residing in Qatar but from Asia (India, Philippines), Middle East (Iran, Jordan, Lebanon, Pakistan, Palestine, Syria, Yemen), North Africa (Egypt, Sudan), and Qatar (Tables 2 and 3). Age-specific seroprevalence values were significantly different across regions for both viruses in all age groups \((P < 0.05\) for all), with the exception of anti-CHIKV IgG seroprevalence for adults \(\geq 50\) years \((P = 0.20)\). Overall, the highest seroprevalence estimates for anti-DENV IgG occurred among Asian nationals (74.8% seropositive, 95% CI 69.7–79.5%) and the lowest among Qatari nationals (3.5% seropositive, 95% CI 1.4–7.1%). For anti-CHIKV IgG, the highest seroprevalence also occurred among Asian nationals (13.5% seropositive, 95% CI 10.0–17.8%), and the lowest among Middle East nationals (1.4% seropositive, 95% CI 0.8–2.2%). Regional nationality was significantly associated with the odds of being anti-DENV and anti-CHIKV IgG seropositive in the unadjusted and adjusted models \((P < 0.05\) for all; Table 4).

### Table 2. Estimates of age-specific anti-DENV IgG seroprevalence among blood donors currently residing in Qatar but from Asia (India, Philippines), Middle East (Iran, Jordan, Lebanon, Pakistan, Palestine, Syria, Yemen), North Africa (Egypt, Sudan), and Qatar, from June 2013 to June 2016.

| Age group | Asiaa | Middle Eastb | North Africa | Qatar | P valuec |
|-----------|-------|--------------|--------------|-------|----------|
| Years     | N+ / Total | % (95% CI) | N+ / Total | % (95% CI) | N+ / Total | % (95% CI) | N+ / Total | % (95% CI) |
| < 24      | 7 / 15 | 46.7 (23.9–70.6) | 9 / 111 | 8.1 (4.1–14.3) | 2 / 19 | 10.5 (2.3–29.7) | 0 / 16 | 0 (0–0) | <0.001 |
| 25–29     | 42 / 56 | 75.0 (62.6–84.9) | 12 / 167 | 7.2 (4.0–11.9) | 22 / 61 | 36.1 (24.9–48.5) | 0 / 33 | 0 (0–0) | <0.001 |
| 30–34     | 65 / 85 | 76.5 (66.7–85.0) | 31 / 238 | 13.0 (9.2–17.7) | 17 / 64 | 26.6 (17.0–38.3) | 2 / 35 | 5.7 (1.2–17.1) | <0.001 |
| 35–39     | 47 / 61 | 77.1 (65.4–86.2) | 29 / 231 | 12.6 (8.8–17.3) | 20 / 66 | 30.3 (20.2–42.1) | 1 / 38 | 2.6 (0.3–11.7) | <0.001 |
| 40–44     | 32 / 43 | 74.4 (60.1–85.6) | 23 / 198 | 11.6 (7.7–16.6) | 13 / 36 | 36.1 (22.0–52.4) | 2 / 35 | 5.7 (1.2–17.1) | <0.001 |
| 45–49     | 32 / 41 | 78.1 (63.8–88.6) | 13 / 111 | 11.7 (6.7–18.7) | 4 / 20 | 20.0 (7.2–40.8) | 2 / 20 | 10.0 (2.1–28.4) | <0.001 |
| ≥ 50      | 13 / 17 | 76.5 (53.3–91.5) | 23 / 119 | 19.3 (13.0–27.1) | 9 / 30 | 30.0 (16.0–47.7) | 0 / 23 | 0 (0–0) | <0.001 |
| Total     | 238 / 318 | 74.8 (69.7–79.5) | 140 / 1175 | 11.9 (10.1–13.9) | 87 / 296 | 29.4 (24.3–34.9) | 7 / 200 | 3.5 (1.4–7.1) | <0.001 |

“N+” indicates number of positive samples.

- Age information was missing for one individual.
- Age information was missing for two individuals.
- P value for differences between regions.

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### Table 3. Estimates of age-specific anti-CHIKV IgG seroprevalence among blood donors currently residing in Qatar but from Asia (India, Philippines), Middle East (Iran, Jordan, Lebanon, Pakistan, Palestine, Syria, Yemen), North Africa (Egypt, Sudan), and Qatar, 2013–2016.

| Age group | Asiaa | Middle Eastb | North Africa | Qatar | P valuec |
|-----------|-------|--------------|--------------|-------|----------|
| Years     | N+ / Total | % (95% CI) | N+ / Total | % (95% CI) | N+ / Total | % (95% CI) | N+ / Total | % (95% CI) |
| < 24      | 2 / 15 | 13.3 (2.9–36.3) | 2 / 111 | 1.8 (0.4–5.7) | 0 / 19 | 0 (0–0) | 0 / 16 | 0 (0–0) | 0.039 |
| 25–29     | 7 / 56 | 12.5 (5.8–23.0) | 4 / 167 | 2.4 (0.8–5.6) | 3 / 61 | 4.9 (1.4–12.6) | 1 / 33 | 3.0 (0.3–13.3) | 0.026 |
| 30–34     | 10 / 85 | 11.8 (6.21–19.9) | 3 / 238 | 1.3 (0.4–3.3) | 4 / 64 | 6.3 (2.2–14.2) | 3 / 35 | 8.6 (2.5–21.1) | <0.001 |
| 35–39     | 5 / 61 | 8.2 (3.2–17.0) | 1 / 231 | 0.4 (0.1–2.0) | 4 / 66 | 6.1 (2.1–13.8) | 0 / 38 | 0 (0–0) | 0.001 |
| 40–44     | 9 / 43 | 20.9 (10.9–34.7) | 3 / 198 | 1.5 (0.4–4.0) | 1 / 36 | 2.8 (0.3–12.3) | 1 / 35 | 2.9 (0.3–12.6) | <0.001 |
| 45–49     | 8 / 41 | 19.5 (9.7–33.5) | 0 / 111 | 0 (0–0) | 3 / 20 | 15.0 (4.4–34.9) | 1 / 20 | 5 (0.5–21.1) | <0.001 |
| ≥ 50      | 2 / 17 | 11.8 (2.5–32.7) | 3 / 119 | 2.5 (0.7–6.6) | 1 / 30 | 3.3 (0.4–14.5) | 1 / 23 | 4.3 (0.5–18.6) | 0.203 |
| Total     | 43 / 318 | 13.5 (10.0–17.8) | 16 / 1175 | 1.4 (0.8–2.2) | 16 / 296 | 5.4 (3.1–8.6) | 7 / 200 | 3.5 (1.4–7.1) | <0.001 |

“N+” indicates number of positive samples.

- Age information was missing for one individual.
- Age information was missing for two individuals.
- P value for differences between regions.

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Asian nationals had higher adjusted odds of being seropositive for anti-DENV antibodies compared to nationals of the Middle East (aOR 0.05, 95% CI 0.04–0.07), North Africa (aOR 0.14, 95% CI 0.10–0.20), and Qatar (aOR 0.01, 95% CI 0.01–0.03). Asian nationals also had higher adjusted odds of being seropositive for anti-CHIKV antibodies compared to those from the Middle East (aOR 0.14, 95% CI 0.07–0.27), North Africa (aOR 0.50, 95% CI 0.26–0.96), and Qatar (aOR 0.38, 95% CI 0.15–0.96). Increasing age was also significantly associated with anti-DENV IgG seroprevalence, with individuals \( \geq 50 \) years of age having 3.18 times (95% CI 1.61–6.28) the adjusted odds of being anti-DENV IgG seropositive compared to individuals \(< 24\) years of age (Table 4). However, age was not significantly associated with the adjusted odds of seropositivity for anti-CHIKV IgG. Finally, the adjusted odds of being anti-DENV IgG seropositive was significantly higher among anti-CHIKV IgG seropositive adults, and vice versa (aOR 1.94, 95% CI 1.09–3.44).

**Discussion**

In our study, anti-DENV and anti-CHIKV IgG prevalences were significantly lower among blood donors residing in Qatar who were MENA nationals compared to Asian nationals, though antibodies to both viruses were detected from donors in all regions. This finding underscores the need to better understand the distribution and epidemiology of these pathogens in the MENA region, but it suggests that the overall burden of DENV and CHIKV disease is higher in India and the Philippines than in the MENA countries represented in our study. The results also suggest regional variability within the MENA region.

Our study is the first, to our knowledge, to estimate the seroprevalence of anti-DENV and anti-CHIKV IgG among nationals of Qatar and Syria [1, 2]. We cannot be certain that individuals from these countries developed antibodies as a result of DENV and CHIKV exposure in their home countries or Qatar rather than through traveling or residing in other endemic areas.
countries, or that these antibodies definitively represent prior exposure and not cross-reactions to other pathogens. Nevertheless, these detections suggest the possibility of low, but potentially unrecognized, transmission of DENV and CHIKV in these MENA countries.

Consistent with many other studies, older age was significantly associated with increased odds of DENV exposure in our study [37–40]. Immunity for the infecting DENV serotype (i.e. detection of serum neutralizing antibodies) is considered to be lifelong, though homotypic reinfections (i.e. reinfection by the same serotype) can occur [41, 42]. Hence, the increased odds of DENV exposure with age is in part a function of longer exposure time. Age was not associated with CHIKV exposure in our study, though this association has been observed for CHIKV [37]. Detection of this association may have been limited by the small proportion of CHIKV seropositive samples in our study and that many (41%) participants were 30–39 years of age (generally reflective of the migrant demographic in Qatar) with variable sample sizes in each age group. As a secondary analysis, we grouped countries by overall seroprevalence levels: high (>30% seroprevalence: India, Philippines, Sudan), medium (15–30% seroprevalence: Egypt, Pakistan, Yemen) and low (<15% seroprevalence: Iran, Jordan, Lebanon, Palestine, Qatar, Syria). These seroprevalence values represent practical cutoffs based on the country-level seroprevalences in our study, as there is currently no consensus to classify population seroprevalence as high or low for either virus to our knowledge. However, this did not result in meaningful changes in any of the aforementioned associations compared to the primary analysis. Finally, the adjusted odds of anti-DENV IgG seropositivity was nearly twice as high among anti-CHIKV IgG seropositive individuals compared to seronegative individuals, which is consistent with the co-circulation of these viruses as a result of their shared vectors Ae. aegypti and Ae. albopictus, and suggests the common source exposure to subjects for both pathogens.

**Dengue in the MENA region**

Anti-DENV IgG antibodies were identified among nationals of all countries in our study, with the highest prevalence among Asian nationals (India 62.5% and Philippines 95.8%). Among MENA nationals, those from Sudan (48.5%), Yemen (24.2%), and Pakistan (20.0%) had the highest seroprevalence. This is consistent with the epidemiologic literature, as available studies suggest DENV is widely endemic in Sudan with seroprevalence of 9–49% among general populations, and multiple outbreaks have occurred along the Red Sea coast since the 1980s [5, 43–47]. The risk of DENV exposure may be similarly high in Yemen, in which recent outbreaks have resulted in 19–87% seroprevalence among general populations [8, 48–51]. In Pakistan, serologic and outbreak data suggest DENV is distributed across the country [52–56].

Our present study also identified 5–13% seroprevalence among nationals from Lebanon, Palestine, and Syria, in which no reports of DENV have been published in decades [57, 58]. However, Ae. albopictus and/or Ae. aegypti have been recently reported in these countries, and there are historic reports of DENV transmission in Lebanon, raising the potential for unrecognized transmission or future emergence in these countries [57, 59, 60]. Additionally, our study identified 20.1% seroprevalence among Egyptian nationals. Ae. aegypti is known to be endemic in Egypt and an outbreak was reported in 2015 along the Red Sea Coast, although there is currently a paucity of literature describing the epidemiology of DENV in the country [61–63]. In Jordan, anti-DENV IgG was recently detected in 24% of 892 healthy individuals distributed across the country, representing the first report of anti-DENV seroprevalence in Jordan [64]. As with our data, these data are not direct evidence for local DENV transmission in Jordan, but suggest its possibility. Finally, our study identified 5.3% seroprevalence among Iran nationals, despite no published reports to our knowledge of DENV transmission or Ae. aegypti
occurrence in Iran. However, prior studies have shown 3–7% seroprevalence near the Pakistan border of the country [17, 65, 66]. Vector surveillance is critical in these countries, both to evaluate the risk of DENV transmission and to implement preventive vector control strategies and active case surveillance as indicated.

Chikungunya in the MENA region

Seroprevalence estimates for anti-CHIKV IgG were significantly lower than anti-DENV IgG estimates in all countries in our study, which is consistent with the current serologic evidence in the MENA region and suggests a lower overall burden of CHIKV disease compared to DENV [2]. Yet although the CHIKV seropositivity was proportionally smaller, the country-level anti-CHIKV IgG proportions were similarly distributed to those of anti-DENV IgG in that those nationals with the highest CHIKV exposure (Philippines, India, Sudan) also had the highest DENV exposure. This supports an overlapping distribution of DENV and CHIKV among the countries represented in our study, on account of the viruses’ shared mosquito vectors, *Ae. aegypti* and *Ae. albopictus* [13].

Our study identified 0.5–3.0% anti-CHIKV IgG seroprevalence in Jordan, Lebanon, Palestine and Syria. There have been no published reports of CHIKV transmission in these countries to our knowledge. Given the additional lack of confirmed DENV transmission in these countries, this raises the probability that these results are either false-positive and/or represent cross-reactions with other pathogens, such as alphaviruses related to CHIKV (o’nyong-nyong virus, Semliki Forest virus, and Sindbis virus), which are also known to be endemic in the MENA region [16, 18, 65, 67–69]. CHIKV is known to circulate in Pakistan, Sudan, and Yemen, and several anti-CHIKV serologic surveys and outbreaks have been published [7, 8, 50, 67, 70, 71]. Anti-CHIKV antibodies have also been reported from Egypt in the 1970s and 80s, and the country has experienced recent DENV outbreaks and is known to harbor *Ae. aegypti* [2, 72]. However, to our knowledge, no CHIKV outbreaks have yet been reported in Egypt.

Anti-DENV and anti-CHIKV IgG seroprevalence in Qatar

A seroprevalence of 3.5% for both anti-DENV and anti-CHIKV IgG was detected among Qatari nationals in our study despite that neither *Ae. aegypti*, *Ae. albopictus*, nor autochthonous transmission of either virus, have ever been reported in Qatar to our knowledge. This may represent travel-acquired infections and/or cross-reactions with related viruses. This low seroprevalence does not substantiate the need for routine DENV vaccination in Qatar, particularly given the recommendation that DENV seroprevalence be $\geq 70\%$ in the age group targeted for vaccination to maximize cost-effectiveness and public health impact [73]. Moreover, the risk of transfusion-transmitted DENV or CHIKV through contaminated blood products is likely low given that the presence of IgG likely represents past exposure after the viremic phase of infection has resolved, and that our samples were not collected in a known outbreak setting [74]. Nevertheless, ongoing surveillance for *Ae. aegypti* and *Ae. albopictus* is warranted in the country, given that vector control remains the primary strategy for outbreak prevention and control, and in light of the recent outbreaks that have occurred in neighboring Saudi Arabia and Yemen [4, 8, 49, 75]. The low seroprevalence among Qatari nationals indicates a lack of herd immunity and susceptibility to DENV and CHIKV outbreaks.

Our study has several strengths but also important limitations. Strengths of our study include its large sample size and diverse population. Not only were we able to estimate anti-DENV and anti-CHIKV IgG seroprevalence among adults from MENA countries in which major epidemiologic knowledge gaps exist, but we were also able to compare estimates against
Asian nationals from hyper-endemic countries known to carry a considerable burden of DENV and CHIKV disease. A major limitation of our study is our reliance on IgG ELISA and lack of confirmatory viral neutralization testing, the gold standard for serodiagnosis of arboviruses, which was not performed due to resource limitations. Viral neutralization was performed in only 5% of anti-DENV and 17% of anti-CHIKV serologic studies in the MENA region in our systematic reviews, with cross reactions to antigenically similar viruses identified in multiple studies resulting in lower attributable prevalence [1, 2]. Documented anti-DENV antibody cross-reaction with West Nile virus, yellow fever virus (natural and vaccine), Zika virus (e.g. in India and Philippines), or other flaviviruses may account for some of the observed seropositivity in our study, while for anti-CHIKV antibodies, cross-reactions to o’nyong-nyong virus, Semliki Forest virus, and Sindbis virus may have occurred. The lack of travel history limits conclusions that can be made regarding other countries, where DENV and CHIKV exposure may have occurred. The lack of IgM or PCR testing limits inference concerning the timing of infections or occurrences of co-infections. Finally, our limited sample of adult male migrants residing in Qatar may not be representative of the general populations in their respective countries (including females), nor adequately matched to one another for the region-level analyses, although the vast majority of these migrants arrived in Qatar in recent years [27, 28]. Given these limitations, caution must be maintained in extrapolating the serologic results in our study to the broader country or region levels [15].

**Conclusion**

Exposure to DENV and CHIKV is low among Qatar and other MENA nationals compared to Asian nationals, suggesting a lower burden of DENV and CHIKV disease in the MENA countries. Antibodies to both viruses were detected in nationals from all MENA countries except Iran, supporting the need for further research to understand the epidemiology of DENV and CHIKV, and the co-circulating viruses that cause serologic cross-reactions, in the MENA. The findings in our study do not support the need for travellers to Qatar to take measures to prevent DENV and CHIKV infections while in Qatar. Surveillance for *Ae. aegypti* and *Ae. albopictus* should be implemented in countries in which autochthonous transmission of DENV or CHIKV has not yet been reported.

**Supporting information**

S1 Table. Raw dataset containing anti-DENV and anti-CHIKV IgG results.
(XLSX)

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References

1. Humphrey JM, Cleton NB, Reusken CB, Glesby MJ, Koopmans MP, Abu-Raddad LJ. Dengue in the Middle East and North Africa: A Systematic Review. PLoS Negl Trop Dis. 2016; 10(12):e0005194. https://doi.org/10.1371/journal.pntd.0005194 PMID: 27926925

2. Humphrey JM, Cleton NB, Reusken C, Glesby MJ, Koopmans MPG, Abu-Raddad LJ. Urban Chikungunya in the Middle East and North Africa: A systematic review. PLoS Negl Trop Dis. 2017; 11(6): e0005707. https://doi.org/10.1371/journal.pntd.0005707 PMID: 28651007

3. World Health Organization Regional Office for the Eastern Mediterranean. Dengue in Pakistan. Wkly Epi Monitor. 2013; 6(52). Available from: www.emro.who.int/surveillance-forecasting-response/weekly-epidemiological-monitor/. Accessed 7 May 2018.

4. World Health Organization Regional Office for the Eastern Mediterranean. Dengue fever in Yemen. 2010; 3(23). Available from: www.emro.who.int/surveillance-forecasting-response/weekly-epidemiological-monitor/. Accessed 7 May 2018.

5. World Health Organization Regional Office for the Eastern Mediterranean. Dengue fever in Sudan: cases continue to rise. 2010; 3(11). Available from: www.emro.who.int/surveillance-forecasting-response/weeklyepidemiological-monitor/. Accessed 5 May 2018.

6. World Health Organization Regional Office for the Eastern Mediterranean. Chikungunya Outbreak in Pakistan. Wkly Epi Monitor. 2017; 10(19). Available from: http://www.emro.who.int/surveillance-forecasting-response/weekly-epidemiological-monitor/. Accessed 2 May 2018.

7. Gould LH, Osman MS, Farnon EC, Griffith KS, Godsey MS, Karch S, et al. An outbreak of yellow fever with concurrent chikungunya virus transmission in South Kordofan, Sudan, 2005. Trans R Soc Trop Med Hyg. 2008; 102(12):1247–54. https://doi.org/10.1016/j.trstmh.2008.04.014 PMID: 18502458

8. Malik MR, Mnzava A, Mohareb E, Zayed A, Al Kohlani A, Thabet AAK, et al. Chikungunya outbreak in Al-Hudaydah, Yemen, 2011: Epidemiological characterization and key lessons learned for early detection and control. J Epidemiol Glob Health. 2014; 4(3):203–11. https://doi.org/10.1016/j.jegh.2014.01.004 PMID: 25107656

9. The World Bank Group. Climate Change Knowledge Portal. Washington D.C., 2018. Available from: http://sdwebx.worldbank.org/climateportal/. Accessed 15 October 2018.

10. Ducheyne E, Tran Minh NN, Haddad N, Bryssinckx W, Buliva E, Simard F, et al. Current and future distribution of Aedes aegypti and Aedes albopictus (Diptera: Culicidae) in WHO Eastern Mediterranean Region. Int J Health Geogr. 2018; 17(1):4. https://doi.org/10.1186/s12942-018-0125-0 PMID: 29444675

11. Qatar Ministry of Development Planning and Statistics. Qatar’s Fourth National Human Development Report: Realising Qatar National Vision 2030, The Right to Development. Doha, Qatar 2015. Available from: http://hdr.undp.org/sites/default/files/qatar_nhdr4_english_15june2015.pdf. Accessed 7 May 2018.

12. Bhatt S, Gething PW, Brady OJ, Messina JP, Farlow AW, Moyes CL, et al. The global distribution and burden of dengue. Nature. 2013; 496(7446):504–7. https://doi.org/10.1038/nature12060 PMID: 23563266

13. Weaver SC, Lecuit M. Chikungunya virus and the global spread of a mosquito-borne disease. N Engl J Med. 2015; 372(13):1231–9. https://doi.org/10.1056/NEJMc1406035 PMID: 25806915

14. Bravo L, Roque VG, Brett J, Dizon R, L’Azou M. Epidemiology of dengue disease in the Philippines (2000–2011): a systematic literature review. PLoS Negl Trop Dis. 2014; 8(11):e3027. https://doi.org/10.1371/journal.pntd.0003027 PMID: 25375119

15. De Bel-Air F. Demography, Migration, and Labour Market in Qatar, Explanatory Note No. 8/2014. European University Institute and Gulf Research Center. Gulf Labour Market and Migration programme of the Migration Policy Center (MPC) and the Gulf Research Center; 2014. Available at: http://gulfmigration.eu Available at. Accessed March 20, 2018.
16. Barakat AM, Smura T, Kuivanen S, Huhtamo E, Kurkela S, Putkuri N, et al. The Presence and Seroprevalence of Arthropod-Borne Viruses in Nasiriyah Governorate, Southern Iraq: A Cross-Sectional Study. Am J Trop Med Hyg. 2016; 94(4):794–9. https://doi.org/10.4269/ajtmh.15-0622 Epub 2016 Feb 15. PMID: 26880770

17. Aghaie A, Aaskov J, Chinkar S, Niedrig M, Banazadeh S, Mohammadpour HK. Frequency of dengue virus infection in blood donors in Sistan and Baluchestan province in Iran. Transfus Apher Sci. 2014; 50(1):59–62. https://doi.org/10.1016/j.transci.2013.07.034 PMID: 24332363

18. Ibrahim SH, Darwish MA, Wahdan MH, el-Ghoroury AA. Serologic survey of Kuwait population for evidence of group A arbovirus infection. J Egypt Public Health Assoc. 1973; 48(5):308–24. PMID: 4789151

19. Ibrahim SH, Darwish MA, Wahdan MH, Eli-Ghoroury AAA. Survey for antibodies against group B arboviruses in man in Kuwait. J Egypt Public Health Assoc. 1974; 49(2):77–95. PMID: 4427084

20. Ergunay K, Saygan MB, Aydogan S, Litzba N, Niedrig M, Pinar A, et al. Investigation of dengue virus and yellow fever virus seropositivities in blood donors from central/Northern Anatolia, Turkey. Mikrobiyoloji Bulteni. 2010; 44(3):415–24. PMID: 21063991

21. Tezcan S, Kizildamar S, Ulger M, Aslan G, Tiftik N, Ozkul A, et al. Flavivirus seroepidemiology in blood donors in Mersin province, Turkey. Mikrobiyoloji bulteni. 2014; 48(4):606–7. PMID: 25492656

22. Ashshi AM. Serodetection of Dengue virus and its antibodies among blood donors in the western region of Saudi Arabia: a preliminary study. Blood Transfus. 2015; 13(1):135–8. https://doi.org/10.2450/2014.0134-14 PMID: 25369603

23. AbuOdeh R, Al-Mawlawi N, Al-Tahtani AA, Bohol MF, Al-Ahdal MN, Hasan HA, et al. Detection and genotyping of torque teno virus (TTV) in healthy blood donors and patients infected with HBV or HCV in Qatar. J Med Virol. 2015; 87(7):1184–91. https://doi.org/10.1002/jmv.24146 PMID: 25676255

24. AbuOdeh RO, Al-Absi E, Ali NH, Khalili M, Al-Mawlawi N, Hadwan TA, et al. Detection and phylogenetic analysis of human pegivirus (GBV-C) among blood donors and patients infected with hepatitis B virus (HBV) in Qatar. J Med Virol. 2015; 87(12):2074–81. https://doi.org/10.1002/jmv.24289 PMID: 26058920

25. Al-Qtantani AA, Alabsi ES, AbuOdeh R, Thalib L, El Zowalaty ME, Nasrallah GK. Prevalence of anelloviruses (TTV, TTMDV, and TTMV) in healthy blood donors and in patients infected with HBV or HCV in Qatar. Virol J. 2016; 13(1):208. https://doi.org/10.1186/s12985-016-0664-6 PMID: 28031027

26. Nasrallah GK, Al Absi ES, Ghandour R, Ali NH, Taleb S, Hedaya L, et al. Seroprevalence of hepatitis E virus among blood donors in Qatar (2013–2016). Transfusion. 2017; 57(7):1801–7. https://doi.org/10.1111/trf.14116 PMID: 28453178

27. Dargham SR, Nasrallah GK, Al-Abisi ES, Mohammed LI, Al-Disi RS, Nofal MY, et al. Herpes Simplex Virus Type 2 Seroprevalence among Different National Populations of Middle East and North African Men. Sex Transm Dis. 2018; 45(7):482–487. https://doi.org/10.1097/OLQ.0000000000000791 PMID: 29465656

28. Nasrallah GK, Dargham SR, Mohammed LI, Abu-Raddad LJ. Estimating seroprevalence of herpes simplex virus type 1 among different Middle East and North African male populations residing in Qatar. J Med Virol. 2018; 90(1):184–90. https://doi.org/10.1002/jmv.24916 PMID: 28817197

29. NovaTec Immunodiagnostica GmbH. Dengue Virus IgG. Dietzenbach, Germany; 2018. Available from: https://www.novatec-id.com/products/product/dengue-virus-igg.html. Accessed October 22, 2018.

30. Euroimmun. ELISA. Lubeck, Germany; 2017. Available from: https://www.euroimmun.com/products/indications/infektions-serologie/tropenkrankheiten/elisa/. Accessed March 20, 2018.

31. Euroimmun. Anti-Dengue Virus ELISA (IgG). Lubeck, Germany; 2016. Available from: https://www.euroimmun.com/documents/Indications/Infections/Dengue/EI_266b_D_UK_A.pdf. Accessed March 20, 2018.

32. Prat CM, Flusin O, Panella A, Tenebray B, Lanciotti R, Leparc-Goffart I. Evaluation of commercially available serologic diagnostic tests for chikungunya virus. Emerg Infect Dis. 2014; 20(12):2129–32. https://doi.org/10.3201/eid2014.121426 PMID: 25418184

33. Mumtaz GR, Weiss HA, Thomas SL, Rione S, Setayesh H, Riedner G, et al. HIV among people who inject drugs in the Middle East and North Africa: systematic review and data synthesis. PLoS medicine. 2014; 11(6):e1001663. https://doi.org/10.1371/journal.pmed.1001663 PMID: 24937136

34. Abu-Raddad LJ, Hilmi N, Mumtaz G, Benkirane M, Akala FA, Riedner G, et al. Epidemiology of HIV infection in the Middle East and North Africa. AIDS. 2010; 24 Suppl 2:S5–23.

35. Harfouche M, Chemaitelly H, Kouyoumjian SP, Mahmoud S, Chaabna K, Al-Kanaani Z, et al. Hepatitis C virus viremic rate in the Middle East and North Africa: Systematic synthesis, meta-analyses, and meta-regressions. PLoS One. 2017; 12(10):e0187177. https://doi.org/10.1371/journal.pone.0187177 PMID: 29088252
36. Mahmud S, Al-Kanaani Z, Chemaitelly H, Chaabna K, Kouryounjian SP, Abu-Raddad LJ. Hepatitis C virus genotypes in the Middle East and North Africa: Distribution, diversity, and patterns. J Med Virol. 2018; 90(1):131–41. https://doi.org/10.1002/jmv.24921 PMID: 28842995

37. Vongpunsawad S, Intharasonkor D, Thongmee T, Poovorawan Y. Seroprevalence of antibodies to dengue and chikungunya viruses in Thailand. PloS one. 2017; 12(6):e0180560. https://doi.org/10.1371/journal.pone.0180560 PMID: 28662144

38. Low SL, Lam S, Wong WY, Teo D, Ng LC, Tan LK. Dengue seroprevalence of healthy adults in Singapore: serosurvey among blood donors, 2009. Am J Trop Med Hyg. 2015; 93(1):40–5. https://doi.org/10.4269/ajtmh.14-0671 PMID: 26013376

39. Ranjan P, Natarajan V, Bajpai M, Gupta E. High Seroprevalence of Dengue Virus Infection in Blood Donors From Delhi: A Single Centre Study. J Clin Diagn Res. 2016; 10(1):DC08–DC10. https://doi.org/10.7860/JCDR/2016/21262.8711 PMID: 26845762

40. Alera MT, Srikiatkachorn A, Velasco JM, Tac-An IA, Lago CB, Clapham HE, et al. Incidence of Dengue Virus Infection in Adults and Children in a Prospective Longitudinal Cohort in the Philippines. PLoS Negl Trop Dis. 2016; 10(2):e0004337. https://doi.org/10.1371/journal.pntd.0004337 PMID: 26845762

41. Murphy BR, Whitehead SS. Immune response to dengue virus and prospects for a vaccine. Annu Rev Immunol. 2011; 29:587–619. https://doi.org/10.1146/annurev-immunol-031210-101315 PMID: 21219187

42. Forshey BM, Stoddard ST, Morrison AC. Dengue Viruses and Lifelong Immunity: Reevaluating the Conventionnal Wisdom. J Infect Dis. 2016; 214(7):979–81. https://doi.org/10.1093/infdis/jiw102 PMID: 26984147

43. Ibrahim SA, Mustafa OM, Mukhtar MM, Saleh EA, El Mubarak HS, Abdallah A, et al. Measles in suburban Khartoum: An epidemiological and clinical study. Trop Med Int Health. 2002; 7(5):442–9. PMID: 12000654

44. Malik A, Earhart K, Mohareb E, Saad M, Saeed M, Ageep A, et al. Dengue hemorrhagic fever outbreak in children in Port Sudan. J Infect Public Health. 2011; 4(1):1–6. https://doi.org/10.1016/j.jiph.2010.08.001 PMID: 21338953

45. Himatt S, Osman KE, Okoued SI, Seidahmed OE, Beatty ME, Soghaier MA, et al. Sero-prevalence of dengue infections in the Kassala state in the eastern part of the Sudan in 2011. J Infect Public Health. 2015.

46. Soghaier MA, Mahmood SF, Pasha O, Azam SI, Karsani MM, ElMangory MM, et al. Factors associated with dengue fever IgG sero-prevalence in South Kordofan State, Sudan, in 2012: Reporting prevalence ratios. J Infect Public Health. 2014; 7(1):54–61. https://doi.org/10.1016/j.jiph.2013.07.006 PMID: 24210245

47. Adam I, Jumaa AM, Elbashir HM, Karsany MS. Maternal and perinatal outcomes of dengue in PortSudan, Eastern Sudan. Virology J. 2010; 7(153).

48. Bin Ghouth AS, Amarasinghe A, Letson GW. Dengue outbreak in Hadramout, Yemen, 2010: an epidemiological perspective. Am J Trop Med Hyg. 2012; 86(6):1072–6. https://doi.org/10.4269/ajtmh.2012.11-0723 PMID: 22665621

49. Madani TA, Abuelzein ETME, Al-Bar H, Azhar EI, Kao M, Aloshoeb HO, et al. Outbreak of viral hemorrhagic fever caused by dengue virus type 3 in Al-Mukalla, Yemen. BMC Infect Dis. 2013; 13(1).

50. Rezza G, El-Sawaf G, Faggioni G, Vescio F, Al Ameri R, De Santis R, et al. Co-circulation of Dengue and Chikungunya Viruses, Al Hudaydah, Yemen, 2012. Emerg Infect Dis. 2014; 20(8):1351–4. https://doi.org/10.3201/eid2008.131615 PMID: 25061762

51. Qassem MAM, Jaawal AAT. Dengue fever or West Nile virus outbreak? Yemen 2013. Int J Infect Dis. 2014; 21:457.

52. Hisam A, Mahmood ur R, Khan MB, Kadir E, Azam N. Frequency of co-existence of dengue and malaria in patients presenting with acute febrile illness. JPMA J Pak Med Assoc. 2014; 64(3):247–51. PMID: 24864593

53. Assir MZK, Masood MA, Ahmad HI. Concurrent dengue and malaria infection in Lahore, Pakistan during the 2012 dengue outbreak. Int J Infect Dis. 2014; 18(1):41–6.

54. Kidwai AA, Jamal Q, Saher, Mehrunnisa, Farooqi FU, Saleem U. Serodiagnosis of dengue infection using rapid immunochromatography test in patients with probable dengue infection. J Pak Med Assoc. 2010; 60(11):936–9. PMID: 21375198

55. Ilaj T, Ilaj S, Aslam S, Ahmad BM, Raja SA. A laboratory based study of dengue epidemic in the city of Lahore during year 2011. Int J Infect Dis 2014; 21:136.

56. Khan E, Kisat M, Khan N, Nasir A, Ayub S, Hasan R. Demographic and clinical features of dengue fever in Pakistan from 2003–2007: A retrospective cross-sectional study. PLoS ONE. 2010; 5(9):1–7.
57. Garabedian GA, Matossian RM, Musalli MN. Serologic evidence of arbovirus infection in Lebanon. J Med Liban. 1971; 24(4):339–50. PMID: 5149804
58. Hatem J. The role of the laboratory in the surveillance of viral diseases in Lebanon. J Med Liban. 1972; 25(3):151–65. PMID: 5086703
59. Haddad N, Habibch RE, Chamat S, Bouharoun-Tayoun H. Presence of Aedes albopictus in Lebanon and Syria. J Am Mosq Control Assoc. 2007; 23(2):226–8. https://doi.org/10.2987/8756-971X(2007)23[226:POAILJ.2.0.CO;2 PMID: 17847859
60. Adawi SHAA. Presence of Aedes albopictus in Palestine—West Bank. Int J Trop Dis Health. 2012; 2(4):301–10.
61. Mohammed YS, Gresikova M, Adamyova K, Ragib AHe-DK. Studies on arboviruses in Egypt. II. Contribution of arboviruses to the aetiology of undiagnosed fever among children. J Hyg. 1970; 68(3):491–5. PMID: 5272347
62. Darwish MA, Ibrahim AH. Prevalence of antibodies to arboviruses in Egypt. Results of a serologic survey among 1,113 university students. Am J Trop Med Hyg. 1975; 24(6 I):981–5.
63. World Health Organization. Dengue Fever—Egypt 2015. Available from: http://www.who.int/csr/don/12-november-2015-dengue/en/. Accessed 7 May 2018.
64. Obaidat MM RA. First report on seroprevalence and risk factors of dengue virus in Jordan. Trans R Soc Trop Med Hyg. 2018; 112(6):279–84. https://doi.org/10.1093/trstmh/try055 PMID: 29992312
65. Saidi S. Survey of antibodies to arboviruses in human population of Iran. Pahlavi Med J. 1971; 2(3):485–90.
66. Chinikar S, Ghiasi SM, Shah-Hosseini N, Mostafavi E, Moradi M, Khakifirouz S, et al. Preliminary study of dengue virus infection in Iran. Travel Med Infect Dis. 2013; 11(3):166–9. https://doi.org/10.1016/j.tmaid.2012.10.001 PMID: 23194952
67. Darwish MA, Hoogstraal H, Roberts TJ, Ahmed IP, Omar F. A sero-epidemiological survey for certain arboviruses (Togaviridae) in Pakistan. Trans R Soc Trop Med Hyg. 1983; 77(4):442–5. PMID: 6314612
68. Woodruff PWR, Morrill JC, Burans JP, Hyams KC, Woody JN. A study of viral and rickettsial exposure and causes of fever in Juba, southern Sudan. Trans R Soc Trop Med Hyg. 1988; 82(5):761–6. PMID: 2855284
69. Salim AR, Porterfield JS. A serological survey on arbovirus antibodies in the Sudan. Trans R Soc Trop Med Hyg. 1973; 67(2):206–10. PMID: 4784057
70. World Health Organization Regional Office for the Eastern Mediterranean. Chikungunya in Somalia. Wkly Epi Monitor. 2016; 9(24). Available from: www.emro.who.int/surveillance-forecasting-response/weekly-epidemiological-monitor/. Accessed 7 May 2018.
71. ProMED-mail. Viral hemorrhagic fever: (Darfur) fatal, WHO, MOH. ProMED-mail. 2015. 25 Oct: 20151102.3760616. <http://www.promedmail.org>. Accessed 7 May 2018.
72. Abozeid S EA, Schaffner F, Samy AM. Re-emergence of Aedes aegypti in Egypt. Lancet Infect Dis. 2018; 18(2):142–3.
73. World Health Organization. Dengue vaccine: WHO position paper–July 2016. Wkly Epidemiol Rec. 2016; 91:349–64. PMID: 27476189
74. Busch MP, Sabino EC, Brambilla D, Lopes ME, Capuani L, Chowdhury D, et al. Duration of Dengue Viremia in Blood Donors and Relationships Between Donor Viremia, Infection Incidence and Clinical Case Reports During a Large Epidemic. J Infect Dis. 2016; 214(1):49–54. https://doi.org/10.1093/infdis/jiw122 PMID: 27302934
75. Aziz AT, Al-Shami SA, Mahyoub JA, Hatabbi M, Ahmad AH, Rawi CSM. An update on the incidence of dengue gaining strength in Saudi Arabia and current control approaches for its vector mosquito. Parasit Vectors. 2014; 7(1). https://doi.org/10.1186/s13071-014-0467-9