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Original article

# Seroprevalence of dengue IgG and associated risk factors in symptomatic and asymptomatic adults in Posadas (Misiones, Argentina), 2017-2019

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ABSTRACT

*Background:* Dengue represents a major public health problem in the Americas in general, and in Posadas (Misiones, Argentina) in particular. This study aimed to assess the seroprevalence of dengue virus infection, analyze associated factors, and determine the proportion of asymptomatic cases.
*Methods:* This prospective cross-sectional study took place from November 2017 to April 2019 in the High Complexity Laboratory of Misiones, at the School Hospital Dr. Ramón Madariaga in Posadas. A random sample of 301 adults (≥ 15 years) was selected from the electoral registry and stratified by geographical area of residence. Sociodemographic, clinical, and laboratory data were collected by means of a survey and serology. Results were analyzed using multivariable logistic regression.
*Results:* The median age of the sample was 33 years; 66% were women, and 46.5% had completed at least secondary school. Anti-dengue IgG antibodies were present in 40.2% of the sample (95% confidence interval [CI] 34.5–45.9%), including 90% of those who reported dengue and 20.5% who did not (odds ratio [OR] 33.25, 95% CI 15.46–71.51, $p < 0.001$). In the multivariable analysis, adjusted for age, group, gender, and vaccination against yellow fever, seropositivity was associated with having relatives with dengue (adjusted OR 3.96, 95% CI 2.18–7.23; $p < 0.001$).
*Conclusion:* Seroprevalence for dengue in Posadas was higher than estimates based on the notification records, and there was a high proportion of asymptomatic cases. Educational level and having a family member who had suffered from dengue were associated with positive serology.


## Introduction

Dengue fever is an infectious disease caused by an arbovirus of the *Flavivirus* genus, belonging to the *Flaviviridae* family and transmitted by the *Aedes aegypti* mosquito. Considered a global health problem, it affects approximately 390 million people per year [1,2]. Dengue virus (DENV) is the most prevalent arbovirus in the Region of the Americas [3,4], although its predominance has diminished since the emergence of Chikungunya virus in December 2013 and Zika virus in May 2015 [5,6]. The acquisition of DENV is followed by an incubation period of 4 to 10 days, when viremia is triggered with the formation of antibodies (IgM, IgG, and IgA). In subsequent (secondary) infections, IgG is detected at higher levels than in the acute phase. These antibodies remain

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elevated for 10 months and even for life, indicating that a person has been infected with DENV.

In Misiones (Argentina), 21,696 cases were confirmed during the 2015–2016 outbreak [7], and another outbreak with 1600 cases took place in 2019 [8]. These estimates are based solely on positive cases reported by SIVILA (National Epidemiological Laboratory Surveillance System in Argentina), which usually detects an increase in symptomatic dengue cases at times when they are clearly rising [7,8]. However, a significant proportion of DENV infections are asymptomatic or subclinical. Such cases could be significantly more infectious than symptomatic ones [9–11], contributing to transmission dynamics by efficiently infecting the mosquito vectors and perpetuating the circulation of DENV during interepidemic periods. Thus, the study of subclinical infections may provide new insights and contribute to improved approaches to early detection and outbreak response [2,12].

Knowing the seroprevalence of dengue in a community, and more specifically the proportion of people with asymptomatic infection, is also important when deciding to implement a vaccination strategy [9,10]. Indeed, in recent years, both the live attenuated dengue vaccine CYD-TDV [13] and another quadrivalent vaccine (TAK-003; Takeda) [14] have become available, generating the need for policymakers to make decisions on resource allocation for immunization. Reliable information on the true epidemiological situation in specific areas of the Americas could be an important tool for crafting evidence-based policy in that regard.

However, in Argentina and particularly in Misiones Province, few studies of asymptomatic infection have been carried out [15], and none have studied seroprevalence in the population. Therefore, the objectives of this study were (a) to assess the seroprevalence of dengue in residents of Posadas, Misiones, Argentina; (b) to analyze the factors associated with the infection; and (c) to determine the proportion of people who reported knowing they had been infected with dengue and the association with a positive response to anti-DENV IgG antibodies. The findings of this study may have implications for vaccine strategies in Argentina.

## Material and methods

### *Type of study and setting*

A prospective cross-sectional study was performed from November 2017 to April 2019 to detect seropositive individuals in Posadas, the capital city of Misiones Province, which lies on Argentina's border with Brazil and Paraguay (latitude −27°22'1.49"S, longitude −55°53'45.89"W). According to the Electoral Court of Misiones Province, Posadas had a population of 277,564 inhabitants in 2010 [16].

### *Study technique*

Eligible participants were people aged 15 years or older who had resided in Posadas for at least two years prior to inclusion, provided informed consent to participate, and completed the survey and gave blood for serological studies. Pregnant residents were excluded.

The sampling strategy was proportional stratified random sampling, with geographic zones of Posadas city constituting the strata. According to data from the Electoral Court of Misiones Province, Posadas has 227,919 inhabitants, distributed in 10 electoral circuits, grouped into three zones of the city: zone A: circuits 1, 2, and 3 (N = 49,491 inhabitants, 21.7% of the total); zone B: circuits 3 A, 4 and 5 (N = 105,423, 46.3%); and zone C: circuits 4 A, 4B, 6 and 7 (N = 73,005, 32.0%). An expected proportion of seropositivity of 40% was assumed, and an extra percentage of patients was included to account for losses. For an absolute precision of 6% and a confidence level of 95%, a total sample size of 307 was needed. Based on this figure, the number of participants to be included by zone was calculated: zone A (central): 21.72% (N = 67); zone B: 46.3% (N = 142); zone C: 32.0% (N = 98) [17].

From each zone of the city, people were randomly preselected for study inclusion using the Posadas electoral register, with proportional representation by zone. Preselected residents were then contacted in collaboration with primary health care services to invite them to participate in the study. Members of the research team went to the homes of the preselected residents, introduced themselves and the responsible professionals, and explained the project in plain language. Those who expressed interest in participating and were willing to sign informed consent were given the written survey, and a blood sample was drawn ("on site" or in the High-Complexity Laboratory in the city of Posadas) to perform serological studies. If they did not accept, those living in adjacent homes were contacted and invited as alternates. In minors over 15 years of age, the parent or guardian's consent was requested as well (signature of the minor and the guardian).

### *Variables and data collection*

Variables collected on the survey included age (categorized in three groups: 15–24 years, 25–44 years, and ≥ 45 years); highest level of educational attainment (< primary school [illiterate/primary school not completed], primary school [completed primary school], secondary school [completed secondary school], higher education); gender (as perceived by the interviewer); self-reported occupation ((homemaker, student, trades, qualified professionals [teachers, university professionals, and civil servants], unemployed, health care worker, retired, domestic worker)); address (categorized by electoral circuit); and yellow fever vaccination. Socioeconomic status was further investigated through questions on health coverage, entitlement to welfare or social benefits, availability of household utilities, and household income (categories were based on value of the Basic Food Basket from December 2017, using exchange rates with US dollars from 27 December 2017 [https://dolarhistorico.com/], USD 1 = ARS 18.79). Participants also answered specific questions about dengue, starting with whether they believed they had ever been infected. If so, they were asked about their symptoms, type of bleeding, medical care received, need for hospitalization, laboratory confirmation of the diagnosis, and household members who had dengue during the 2015–2016 outbreak.

Following the survey, participants gave a 5 mL blood sample by means of venipuncture. After centrifugation, fractionation, and identification, the tubes were preserved in aliquots of serum and frozen at − 80 °C until processing in the molecular biology sector of the study laboratory. The identification of anti-dengue IgG antibodies was carried out on all the serum samples using the Panbio Dengue IgG Indirect ELISA immunoenzymatic assay kit, following the manufacturer's instructions (Dia. Pro.Diagnostics Bioprobes S.R.L, Sesto San Giovanni, Italy). Reactive samples were classified as dengue infections and were subjected to qualitative determination of IgG antibodies against DENV [17].

To ensure the validity of the results, an analysis of IgG cross-reactivity with other flaviviruses was performed. Fifty-six serum samples were tested for IgG antibodies against the Chikungunya virus using the DIA.PRO CHIKV IgG enzyme-linked immunosorbent assay. The positive samples were processed using the VIRCLIA LOTUS chemiluminescence methodology for detecting IgG antibodies against the Chikungunya virus. Another 18 serum samples that tested negative for IgG antibodies against both DENV and Chikungunya viruses were tested for IgG antibodies against the Zika virus (DIA.PRO ZIKV IgG enzyme-linked immunosorbent assay).

### *Statistical analysis*

Survey data were coded and loaded into an Excel spreadsheet. Categorical variables were expressed as frequencies (percentages)

and compared using Pearson's chi-square test. Differences in seropositivity (yes/no) and other categorical variables were calculated using odds ratios (ORs) with 95% confidence intervals (CIs). Multivariable logistic regression analysis was used to identify independent predictors of positive serology for DENV. Variables yielding a p value of less than 0.1 in the univariable analysis, plus age, gender and vaccination against yellow fever to the outcome (positive serology for DENV), were entered into a multivariable logistic regression, using a stepwise selection method with the likelihood ratio test. Statistical significance was set at $p < 0.05$. All analyses were performed using IBM SPSS Statistics for Windows, Version 25.0 (Armonk, NY IBM Corp).

### *Ethics*

The study protocol was approved by the Teaching and Research Committee of the School Hospital Dr. Ramón Madariaga and by the Research Ethics Committee of the Province of Misiones (CEIP) before the start of the study.

## Results

### *Participant characteristics*

Of the 306 people initially recruited from November 2017 to April 2019, 5 were excluded (1 was pregnant and 4 resided outside the study area), for a final sample of 301 participants. Two-thirds (n = 200) were women, and the median age was 33 years (range 15 to 83). Table 1 shows participants' main socio-epidemiological characteristics, and Fig. 1**a** their geolocation.

**Table 1**
Sociodemographic characteristics of the study population (n = 301).

| Characteristics | | n | (%) |
|---|---|---|---|
| **Gender** | Women | 200 | (66.4) |
| | Men | 101 | (33.6) |
| **Age in years** | **Median 33 (range 15-83)** | | |
| | 15–24 | 88 | (29.2) |
| | 25–44 | 130 | (43.2) |
| | ≥ 45 | 83 | (27.6) |
| **Highest educational attainment** | < Primary school | 20 | (6.6) |
| | Primary school | 91 | (30.2) |
| | Secondary school | 140 | (46.5) |
| | Higher education | 50 | (16.6) |
| **Occupation** | Homemaker | 75 | (24.9) |
| | Student | 70 | (23.3) |
| | Trades | 39 | (13.0) |
| | Retail | 23 | (7.6) |
| | Qualified professional | 23 | (7.7) |
| | Unemployed | 22 | (7.3) |
| | Health care worker | 22 | (7.3) |
| | Retired | 16 | (5.3) |
| | Domestic worker | 11 | (3.7) |
| **Monthly income (USD*) (n = 277)** | < 957.94 | 200 | (72.2) |
| | 957.95 to 1596.59 | 49 | (17.7) |
| | > 1596.59 | 28 | (10.1) |
| **Welfare benefits** | Yes | 134 | (44.5) |
| | No | 167 | (55.5) |
| **Lives alone** | Yes | 28 | (9.3) |
| | No | 273 | (90.7) |
| **Availability of household utilities†** | Yes | 299 | (99.3) |
| | No | 2 | (0.7) |
| **Vaccination against yellow fever (n = 256)** | Yes | 192 | (75) |
| | No | 64 | (25) |
| **Strata** | Zone A (center) | 96 | (31.9) |
| | Zone B | 100 | (33.2) |
| | Zone C (outlying areas) | 105 | (34.9) |

†Household utilities: running water, electricity, garbage collection
* Official exchange rate (for purchasing dollars), 27 Dec 2017: USD 1 = ARS 18.79 (dolarhistorico.com)

### *Seroprevalence of anti-dengue IgG antibodies*

Of the 301 serum samples processed, 121 were positive for anti-dengue IgG antibodies (seroprevalence 40.2%, 95% CI 34.49 to 45.90). Fig. 1**b** shows the geolocation of positive cases.

### *IgG antibodies against Chikungunya virus and Zika virus*

Of the total 56 samples tested for IgG antibodies against Chikungunya virus, the specifications of the initial technique showed 2 equivocal results for Chikungunya (with positive dengue IgG serology), and 1 sample that was positive for both dengue IgG and Chikungunya IgG. All three samples were processed using chemiluminescence methodology, resulting in negative outcomes for Chikungunya. Regarding IgG antibodies against the Zika virus, a random 10% of samples that were negative for dengue (n = 18) were tested, and all yielded negative results for IgG antibodies against Zika.

### *History of clinical dengue and IgG antibody response*

All in all, 28.6% (n = 86) of the sample reported having been infected with dengue, and their diagnosis was confirmed by ELISA in 89.5% (n = 77) of these. Their geographic distribution by residence is shown in Supplementary Fig. S1. Most reported being ill between January 2015 and February 2016 (Supplementary Fig. S2 and S3), though 12.8% (n = 11) did not remember exactly when the infection occurred. Table 2 details the most frequently reported symptoms and their demand for health services. Medical care was necessary in 72% (n = 62), and hospitalization in 7% (n = 6). The most frequent setting for medical care was the public hospital 37% (n = 32). Over half of those who self-reported dengue (58.1%, n = 50) reported having a family member with dengue in the same period as they did.

Of the 215 (71.4%) people who reported no infection with dengue, 20.5% (n = 44) tested positive for anti-dengue IgG antibodies. These are considered possible asymptomatic cases. The differences between asymptomatic and symptomatic cases are described in Supplementary table 1. The difference in seropositivity between symptomatic (89.5%) versus non-symptomatic (20.5%) participants was statistically significant (OR 33.25; 95% CI 15.46 to 71.51; $p < 0.001$ by Pearson's chi-square test).

### *Factors associated with seropositivity for dengue*

Table 3 shows study variables and their association with positive serology for DENV. Compared to people with at least some higher education, those who had stopped their studies at primary or secondary school were at higher risk. Having relatives with DENV was also associated with a two-fold higher risk of seropositivity. No significant associations were observed with respect to age, sex, occupation, monthly income, area of residence, availability of household utilities, or vaccination against yellow fever.

In the multivariable analysis, adjusted for age group, gender, highest educational attainment, occupation, household member with dengue infection, and vaccination against yellow fever, the only factor associated with seropositivity for dengue was having a household member with dengue infection (adjusted OR 3.96, 95% CI 2.18–7.23; $p < 0.001$).

## Discussion

This is the first study of seroprevalence for antibodies against dengue based on a representative sample of the population of Posadas. The geospatial analysis showed no differences in the distribution of cases between different areas of the city. However, our data show that 40.2% of the sample had been infected with dengue. This seroprevalence is higher than a recent (2020–2021) estimate of

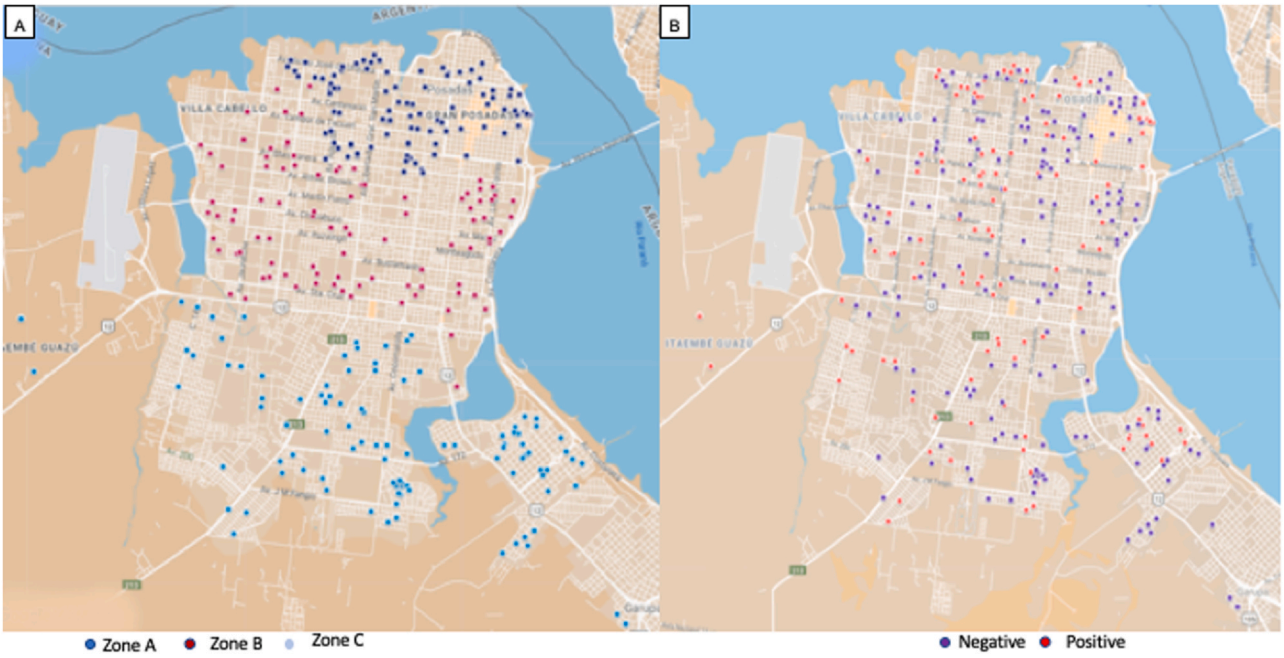


**Fig. 1.** (A) Geographic distribution of study participants in Posadas, Argentina, and (B) distribution according to results of serology tests for anti-dengue IgG antibodies.

**Table 2**
Characteristics of participants who self-reported dengue infections (n = 86).

| Variables | | n | (%) |
|---|---|---|---|
| **Age group** | 15–24 years | 23 | (26.7) |
| | 25–44 years | 39 | (45.3) |
| | ≥ 45 years | 24 | (27.9) |
| **Gender** | Women | 57 | (66) |
| | Men | 29 | (34) |
| **Symptoms** | Headache | 80 | (93.0) |
| | Fever | 79 | (91.9) |
| | Muscle pain | 77 | (89.5) |
| | Joint pain | 69 | (80.2) |
| | Retro-orbital pain | 55 | (64.0) |
| | Rash | 40 | (46.5) |
| | Nausea | 35 | (40.7) |
| | Conjunctival injection | 31 | (36.0) |
| | Vomiting | 30 | (34.9) |
| | Abdominal pain | 26 | (30.2) |
| | Hemorrhagic manifestations* | 18 | (21.0) |
| | Diarrhea | 12 | (14.0) |
| **Medical care** | Yes | 62 | (72.1) |
| | No | 24 | (27.9) |
| **Hospitalization** | Yes | 6 | (7.0) |
| | No | 80 | (93.0) |
| **Health services setting** | Public hospital | 32 | (37.2) |
| | Private health care service | 20 | (23.3) |
| | Primary health care | 11 | (12.8) |
| **Laboratory diagnosis** | Yes | 27 | (31.4) |
| | No | 59 | (72.4) |
| **Vaccination against yellow fever** | Yes | 48 | (55.8) |
| | No | 38 | (44.2) |
| **Household members with dengue infection** | Yes | 50 | (58.1) |
| | No | 36 | (41.9) |
| **Lives alone** | Yes | 6 | (7.0) |
| | No | 80 | (93.0) |

* Petechiae, purpura, epistaxis, gingivorrhagia, hemoptysis, melena

country-wide prevalence in Argentina (14.4%), although that study also showed that the highest prevalence of dengue was concentrated in the northeastern region [18].

Moreover, in our study the proportion of anti-DENV antibodies was significantly higher in people who reported symptoms compared to those who did not, though there was a relevant proportion of asymptomatic participants with DENV infection (20,5%). Our overall results reflect a higher prevalence than the 24.2% reported by Pereira et al. in the Paraguayan Chaco [19] but lower than the 73.6% described by Pavia-Ruz et al. [20] in Yucatán (Mexico) and the 84% described by Chis Ster et al. [21] in Esmeralda (Ecuador).

At the time of sample collection, 28.6% of the participants self-reported a previous dengue infection, less than the 34% observed by Pereira et al. [19] but more than the 5.2% in Pavia-Ruzet al.'s study [20]. The most frequent symptoms reported were headache (93%), fever (91.9%), muscle pain (89.5%), and joint pain (80.2%). In contrast, the dominant symptom in Paraguay was fever (81%) [19]. Among the respondents who reported becoming ill with dengue, 89.5% had the infection serologically confirmed—a much higher proportion than the 45% observed by Pereira et al. [19]. We observed significant differences in seropositivity according to educational attainment and participant-reported dengue fever in household members in the period prior to carrying out the survey.

Of our total sample, 215 (71.6%) reported never having had dengue fever; however, 44 (20.5%) of these participants tested positive for IgG antibodies against DENV, indicating an asymptomatic infection. This proportion was higher than that observed by Pereira et al. [19], who reported a prevalence of asymptomatic cases of 13%, and by Ferri et al. [15] in a university population of Posadas, where 6.6% of asymptomatic cases were reported.

Asymptomatic cases are an indirect indicator of the existence of the vector and of low-level transmission in endemic regions [9–11]. During epidemics or in isolated symptomatic cases, the disease is notified and control interventions applied, but this is not the case for asymptomatic infections. Health systems respond only to symptomatic, notified cases, but active surveillance or systematic seroprevalence studies are better suited to endemic settings, as they characterize the real extent of the problem and ensure adequate epidemiological control.

In addition, the city of Posadas has an entomological surveillance system that periodically reports on the evolution of aedic indices, as recommended by the Pan American Health Organization (PAHO) [3]. The Directorate of Surveillance and Vector Control conducts surveillance of residential *Aedes* infestation using the "Rapid Survey of

**Table 3**
Factors associated with positive serology for dengue in the study population of Posadas, Argentina.

| Variable | | Serology | | | | |
|---|---|---|---|---|---|---|
| | | Positive (n = 121) n (%) | Negative (n = 180) n (%) | OR | 95% CI | p[φ] |
| **Age group** | 15–24 years | 31 (25.6) | 67 (37.2) | 1.00 | – | 0.53 |
| | 25–44 years | 55 (45.5) | 75 (41.7) | 1.20 | 0.84 - 1.69 | |
| | ≥ 45 years | 35 (28.9) | 48 (26.7) | 1.19 | 0.81 - 1.74 | |
| **Gender** | Women | 77 (63.6) | 123 (68.3) | 1.00 | | 0.40 |
| | Men | 44 (36.4) | 57 (31.7) | 1.23 | 0.75 - 2.00 | |
| **Highest educational attainment** | < Primary school | 8 (6.6) | 12 (6.7) | 1.81 | 0.86 - 3.84 | 0.034 |
| | Primary school | 42 (34.7) | 49 (27.2) | 2.09 | 1.19 - 3.69 | |
| | Secondary school | 60 (49.6) | 44 (24.4) | 1.94 | 1.11 - 3.39 | |
| | Higher education | 11 (9.1) | 75 (41.7) | 1.00 | | |
| **Occupation** | Homemaker | 34 (28.1 | 42 (23.2) | 2.08 | 0.92 - 4.70 | 0.091 |
| | Student | 27 (22.3) | 45 /24.9) | 1.72 | 0.75 - 3.95 | |
| | Trades | 13 (10.7) | 23 (12.7) | 1.53 | 0.62 - 3.74 | |
| | Retail | 7 (5.8) | 15 (8.3) | 1.46 | 0.54 - 3.92 | |
| | Qualified professional | 5 (4.1) | 18 (10.0) | 1.00 | – | |
| | Unemployed | 15 (12.4) | 8 (4.4) | 2.87 | 1.24 - 6.62 | |
| | Health care worker | 5 (4.1) | 15 (8.3) | 1.43 | 0.49 - 4.16 | |
| | Retired | 10 (8.3) | 6 (3.3) | 2.70 | 1.13 - 6.46 | |
| | Domestic worker | 5 (4.1) | 8 (4.4) | 1.76 | 0.62 - 4.98 | |
| **Monthly income (USD*)[†]** | < 957.94 | 85 (71.4) | 115 (68.5) | 1.48 | 0.81 - 2.73 | 0.21 |
| | 957.95 to 1596.59 | 16 (13.4) | 33 (19.6) | 1.14 | 0.56 - 2.32 | |
| | > 1596.59 | 8 (6.7) | 20 (11.9) | 1.00 | – | |
| **Strata** | Zone A | 39 (40.6) | 57 (31.7) | 1.06 | 0.75 - 1.51 | 0.85 |
| | Zone B | 38 (38.0) | 62 (34.4) | 1.00 | – | |
| | Zone C | 44 (41.9) | 61 (33.9) | 1.10 | 0.78 - 1.54 | |
| **Household member with dengue infection** | Yes | 63 (52.1) | 42 (23.2) | 3.57 | 2.17 - 5.86 | < 0.005 |
| | No | 58 (47.9) | 138 (76.2) | 1.00 | | |
| **Availability of household utilities[‡]** | Yes | 119 (98.3) | 179 (99.4) | 0.67 | 0.04 - 10.82 | 0.77 |
| | No | 2 (1.7) | 1 (0.6) | 1.00 | | |
| **Lives alone** | Yes | 9 (7.4) | 19 (10.6) | 0.68 | 0.3 - 1.56 | 0.36 |
| | No | 112 (92.6) | 161 (89.4) | 1 | | |
| **Vaccination against yellow fever[§]** | Yes | 72 (70.6) | 120 (77.9) | 0.68 | 0.38 - 1.20 | 0.19 |
| | No | 30 (29.4) | 34 (22.1) | 1.00 | | |

*Official exchange rate (for purchasing dollars), 27 Dec 2017: USD 1 = ARS 18.79 (dolarhistorico.com)
[†] Number of participants with monthly income available with serology positive (n = 109) and serology negative (n = 158)
[‡]Household utilities: running water, electricity, garbage collection
[§]Number of participants with vaccination against yellow fever with serology positive (n = 102) and serology negative (n = 154)
[φ] P value using Pearson's chi-square test

*Aedes aegypti* Infestation" (LIRAa) methodology. In 2015 and 2016, entomological indices indicated a "high risk" of dengue transmission: the house index was over 10% and the Breteau index, over 12% [22].

Among the study's strengths, it has a population-based design, with a proportional sample chosen according to the electoral district of the city of Posadas. Participants were drawn from the electoral register of Argentina, an administrative record managed by the National Electoral Chamber. The continuous updates to this database make it a valid and reliable source that is useful for carrying out research in citizens from a demographic and/or epidemiological perspective. All citizens must renew their national identity card at the age of 14, and those who turn 16 by the date of the general election are obligated to participate in both the primary and general elections. In Posadas, the electoral roll is disaggregated into electoral circuits made up of polling stations. We grouped these circuits by their geographical proximity [16], taking into account key urban characteristics such as location with respect to the center and microcenter of the city. This strategy ensures that the final sample is representative of the Posadas population.

However, the study also has some limitations, such as the lack of IgM determination to identify acute cases and the design of the epidemiological survey, which was not substructured to obtain more information. Another possible limitation could be cross-reactivity with other flaviviruses. To address this, a random sample of sera was tested for Chikungunya (n = 56) and Zika (n = 18) to explore potential cross-reactivity, with unremarkable results. In the same line, no difference was observed in the prevalence of dengue antibodies between the 192 people vaccinated against yellow fever and those who were unvaccinated.

## Conclusions

Our findings demonstrate the substantial impact of local transmission of DENV in Posadas. Notably, 1 in 5 asymptomatic participants had antibodies against DENV. These results offer critical insights on transmission dynamics, which could inform the design of targeted interventions, policy-making, surveillance programs, and vaccine strategies.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jiph.2024.02.002.

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