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Letter to the Editor

Vertical Transmission of Dengue Virus in *Aedes* Mosquitoes: An Overlooked Challenge for Sustainable Dengue Prevention

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Dear Editor

Dengue has become one of the fastest-growing mosquito-borne viral diseases worldwide, causing 390 million infections annually and imposing an enormous burden on public health systems, particularly in tropical and subtropical countries. The World Health Organization (WHO) included dengue among the 10 priorities of its strategic plan. The WHO estimates that 40% of the world's population is at risk of contracting the disease. Despite extensive efforts to control dengue through vector management, outbreaks continue to increase in frequency and geographic extent (1).

Normally, a mosquito becomes infected by biting an affected person; this is known as horizontal transmission (Fig. 1, Upper panel), when the virus passes from a human to a mosquito, then to another human. Another route that keeps the virus circulating locally is vertical transmission (Fig. 1, Lower panel). An important but often overlooked reason for dengue persistence is vertical (transovarial) transmission of the dengue virus (DENV) in *Aedes* mosquitoes. This occurs when a mosquito transmits the virus to its offspring, passing it from an infected female to the eggs, where it remains in the larvae until adulthood. Unlike the conventional cycle, which requires mosquitoes to acquire the virus by feeding on an infected human, vertically infected mosquitoes can emerge already carrying the virus before their first blood meal. Thus, newly infected mosquitoes can transmit the virus without biting any infected person first. These mosquitoes may become infectious soon after emergence, potentially initiating transmission even without an infected human host. The epidemiological significance of vertical transmission has gained increasing scientific attention over the past two decades. Numerous studies have demonstrated natural vertical transmission of all four dengue virus serotypes in both *Aedes aegypti* and *Aedes albopictus* under laboratory and field conditions. Although reported rates are generally low, even infrequent transmission can contribute substantially to long-term virus persistence because mosquito populations are extremely large and reproduce continuously throughout the year (2–4).

Vertical transmission could help keep the virus in an area between epidemics. In endemic areas, the virus may persist through vertical transmission during low-mosquito seasons, when horizontal transmission is less likely. Laboratory studies with *Ae. albopictus* and *Ae. aegypti* have shown that the virus can be transmitted for 3 and 7 consecutive generations, respectively. Vertical transmission under natural conditions has been described in both Asia and America. In Asia, it has been confirmed in Thailand, India, Malaysia, Singapore, Indonesia and the Philippines. In America, it has been detected in Trinidad and Tobago, Bolivia, Argentina, Peru, Mexico, Costa Rica and Brazil (4).

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One major challenge of vertical transmission is its ability to maintain the virus during inter-epidemic periods. In many endemic countries, dengue incidence declines during the dry season when mosquito density is low. This decline was traditionally assumed to interrupt virus circulation. However, vertically infected eggs can survive unfavorable conditions for several months. When rainfall returns and eggs hatch, infected adult mosquitoes may emerge and serve as the initial source of transmission, triggering the next epidemic without reintroduction from infected humans. This mechanism may partly explain the seasonal re-emergence of dengue in endemic regions.

Vertical transmission complicates conventional vector control and can make dengue control difficult. Most programs target adult mosquitoes or larval habitats during outbreaks. While these measures reduce mosquito numbers, they do not eliminate virus-infected eggs already in the environment. *Aedes* eggs resist desiccation and can remain viable for months on the inner surfaces of water-holding containers. Consequently, infected eggs may survive insecticide applications, sanitation campaigns and temporary reductions in mosquito populations. When conditions become favorable, these eggs hatch into infected mosquitoes, allowing the virus to resume. Epidemiological models show outbreaks are harder to control when vertical transmission occurs. Epidemics caused by virus strains that cannot be transmitted vertically may be easier to control. The ability to transmit vertically has a strong genetic component, depending on the virus strain and mosquito populations (5).

The existence of vertical transmission further complicates dengue surveillance. Detection of dengue virus in field-collected eggs, larvae, pupae or newly emerged adult mosquitoes provides strong evidence that the virus has been maintained independently of human infections. Therefore, routine entomological surveillance should extend beyond measuring larval indices such as the House Index, Container Index and Breteau Index. Incorporating molecular detection of dengue virus in immature mosquito stages using reverse transcription polymerase chain reaction (RT-PCR) or real-time RT-PCR may serve as a potential early indicator of viral circulation before human cases increase. Such surveillance would strengthen outbreak prediction and enable earlier implementation of targeted interventions.

Environmental conditions may influence vertical transmission. It was shown that mosquitoes are more likely to hatch from eggs that hatch slowly when conditions favor larval development. It is believed that eggs taking longer to hatch allow the virus to replicate more and become more abundant until it infects the embryo. Thus, during less favorable breeding periods, vertical transmission could be especially relevant. During droughts, when eggs remain in this stage longer waiting for rains to allow larval development, more mosquitoes infected by the mother are expected (6). During droughts, mosquitoes can become more aggressive, bite more and increase disease transmission risk. Climate change, rapid urbanization, inadequate water management and rising insecticide resistance further amplify vertical transmission's importance. Warmer temperatures accelerate mosquito development and viral replication, while prolonged rainy seasons create abundant breeding habitats. Under these conditions, vertically infected mosquito populations may establish stable reservoirs, making dengue elimination more difficult.

Understanding vertical transmission has become increasingly important as dengue has expanded rapidly into rural and peri-urban regions as an emerging dengue hotspot. Recent dengue epidemics have demonstrated that transmission is no longer confined to major metropolitan areas. The emergence of new dengue hotspots in rural regions raises important questions about the mechanisms underlying long-term viral persistence. Investigating vertical transmission among local *Aedes* populations could help explain why outbreaks recur annually despite seasonal declines in reported human infections (7).

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Future dengue control strategies should therefore adopt a more comprehensive approach. In addition to conventional source reduction, integrated vector management should include continuous surveillance for vertically transmitted dengue virus, monitoring of infected eggs and larvae, improved ovitrap surveillance, community participation in eliminating egg-laying habitats, and research into innovative interventions such as *Wolbachia*-based mosquito control, sterile insect techniques and genetically modified mosquitoes. Mathematical transmission models should also incorporate vertical transmission parameters to improve outbreak forecasting and evaluation of control interventions (7). Although vertical transmission alone cannot sustain large dengue epidemics, it is an important ecological mechanism that enables the dengue virus to persist between epidemic seasons. Ignoring this hidden transmission pathway may partly explain why dengue remains difficult to eliminate despite decades of vector control. Greater investment in research on vertical transmission, especially in the emerging dengue hotspots, will improve understanding of dengue ecology and contribute to more effective and sustainable control strategies.

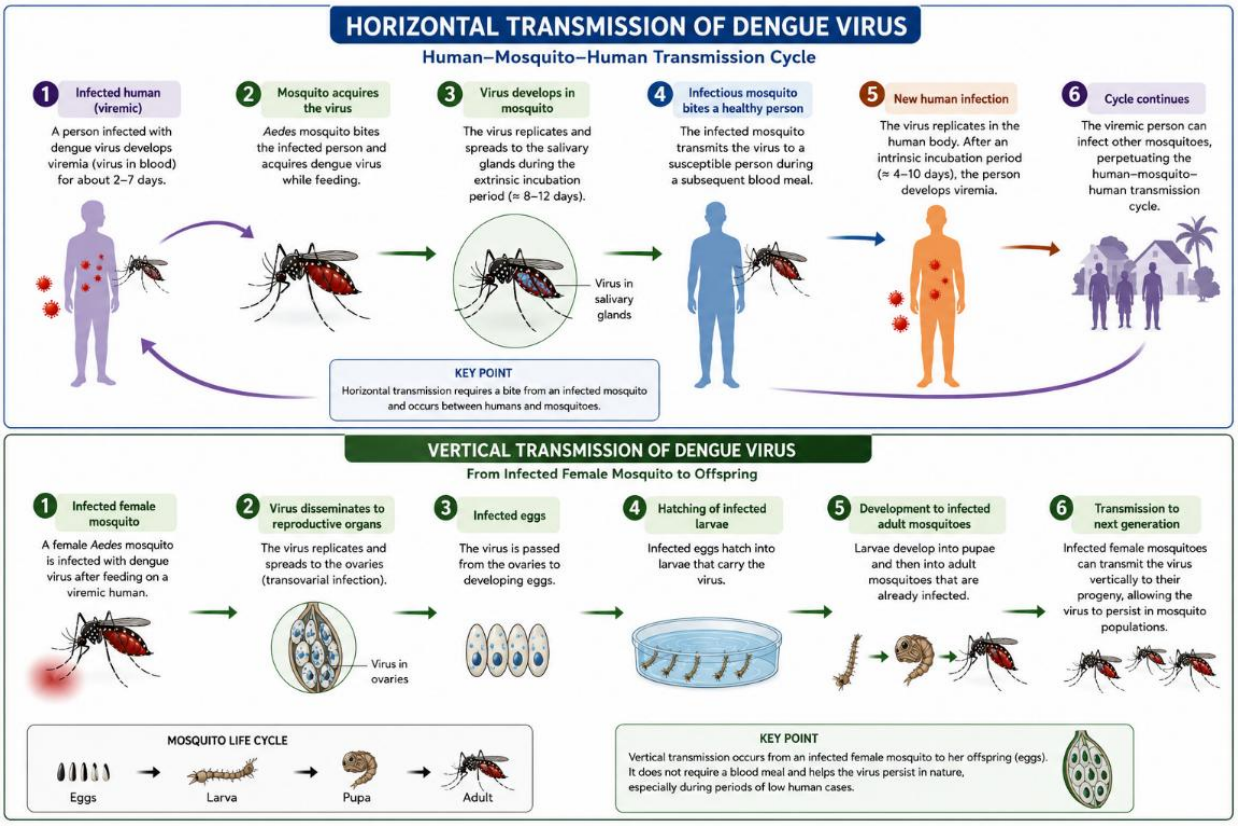


Fig. 1. Dengue virus transmission: horizontal transmission (Upper panel) and vertical (transovarial) transmission (Lower panel) (8)

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Conflict of interest statement

The authors declare that there are no conflicts of interest.

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