



Confronting Dengue: Innovations in Surveillance, Vaccines, and Vector Control

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Perspective

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Abstract

Dengue remains one of the most rapidly expanding mosquito-borne viral diseases, affecting millions of people annually across tropical and subtropical regions. Increasing urbanization, climate change, globalization, and the widespread distribution of *Aedes* mosquitoes have accelerated dengue transmission, transforming it into a major global public health concern. While supportive clinical management has reduced mortality in many countries, sustainable control remains challenging due to the absence of universally effective antiviral therapies and the complex epidemiology of the four dengue virus serotypes. Recent advances in genomic surveillance, artificial intelligence, digital health technologies, vaccine development, and innovative vector control strategies are reshaping dengue prevention and response. These emerging approaches provide opportunities for earlier outbreak detection, improved risk prediction, enhanced immunization programs, and more sustainable mosquito control. This perspective discusses recent developments in dengue surveillance, vaccines, and vector management while highlighting the importance of integrated public health policies, multidisciplinary collaboration, and continued investment in research. Strengthening these interconnected strategies will be essential to reducing the global burden of dengue and improving preparedness for future outbreaks.

Keywords: Dengue virus; Vector surveillance; Vaccine development; *Aedes aegypti*; Public health; Genomic surveillance; Vector control; Emerging infectious diseases

Introduction

Dengue has become one of the defining vector-borne infectious diseases of the twenty-first century. Once considered a regional health concern, it now threatens nearly half of the global population, with transmission reported in more than 100 countries. The disease continues to expand beyond its traditional geographical boundaries, reflecting the combined influence of climate variability, rapid urban growth, international travel, and increasing human mobility. These interconnected factors have created favorable conditions for the widespread establishment of

Aedes aegypti and *Aedes albopictus*, the principal mosquito vectors responsible for dengue transmission.

The dengue virus (DENV), belonging to the *Flaviviridae* family, comprises four genetically and antigenically distinct serotypes (DENV-1 to DENV-4). Infection with one serotype generally provides lifelong immunity against that specific serotype but offers only temporary cross-protection against the remaining serotypes. Consequently, secondary infections may result in more severe disease through complex immunological mechanisms such as antibody-dependent enhancement. This unique characteristic continues to

complicate vaccine development, clinical management, and long-term disease control [1].

The growing frequency of dengue outbreaks demonstrates that conventional public health interventions alone are no longer sufficient. Many endemic countries continue to rely heavily on insecticide spraying and community awareness campaigns; however, insecticide resistance, inconsistent implementation, and environmental changes have reduced the long-term effectiveness of these traditional approaches. At the same time, advances in molecular biology, computational science, vaccine technology, and digital epidemiology have created new opportunities to transform dengue prevention and control.

This perspective highlights recent innovations that are reshaping dengue management, emphasizing integrated surveillance systems, next-generation vaccines, and novel vector control technologies. Rather than viewing these approaches as independent interventions, future dengue control should adopt a coordinated strategy that combines scientific innovation with strong public health infrastructure and community engagement.

Innovations in Dengue Surveillance

Effective surveillance remains the cornerstone of dengue prevention. Early identification of outbreaks allows health authorities to implement timely vector control measures, strengthen clinical preparedness, and reduce disease transmission before widespread community spread occurs. Traditional surveillance systems, which primarily depend on clinical case reporting and laboratory confirmation, continue to play an essential role but often experience delays that limit rapid public health responses [2].

Recent technological advances are transforming surveillance into a more proactive and predictive system. Whole-genome sequencing now enables researchers to monitor circulating dengue virus serotypes, identify viral evolution, and investigate transmission pathways with unprecedented precision. Genomic surveillance not only improves outbreak investigations but also supports vaccine evaluation by monitoring genetic diversity among circulating viral strains.

Artificial intelligence (AI) and machine learning have emerged as valuable tools for predicting dengue outbreaks. By integrating meteorological information, mosquito density, historical case reports, environmental conditions, and population movement, predictive algorithms can estimate outbreak risks several weeks before case numbers begin to rise. Such forecasting systems allow public health agencies to allocate resources more efficiently and initiate preventive interventions in high-risk communities.

Digital health platforms have also strengthened real-time disease surveillance. Mobile health applications enable rapid case reporting by healthcare providers, while cloud-based databases facilitate information sharing among laboratories, hospitals, and public health authorities. Geographic Information Systems (GIS) further improve surveillance by identifying disease hotspots, monitoring vector distribution, and supporting targeted vector control campaigns.

Wastewater surveillance and environmental monitoring, although more commonly associated with respiratory viruses, are increasingly being investigated as complementary tools for vector-borne disease surveillance. Combined with entomological monitoring, these approaches may improve understanding of dengue transmission dynamics in urban environments.

Importantly, surveillance should extend beyond laboratory technologies. Community participation remains a critical component of successful dengue control. Local reporting of mosquito breeding sites, active community engagement, and health education programs significantly improve early detection and support sustainable vector management. The future of dengue surveillance will therefore depend on integrating advanced technologies with strong public health systems and community-based initiatives.

References

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