Review

A Review of the Latest Control Strategies for Mosquito-Borne Diseases

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ABSTRACT

Mosquito-borne diseases are persistent and potentially severe posing a threat to global pandemic preparedness. The risk of mosquito-borne virus transmission is rapidly increasing due to the unprecedented spread of viruses such as dengue and chikungunya, the disruption of global mosquito-borne disease control efforts following the emergence of coronavirus diseases 2019 (COVID-19) in 2019, global warming, and human activities. To address this global challenge, various innovative mosquito control technologies are being developed worldwide. This paper summarizes the latest advances in mosquito vector control, focusing on China's latest mosquito control strategies, to provide insights into implementing novel mosquito-borne disease control measures.

Global Overview of Mosquito-Borne Disease and Progress in Prevention and Control

In recent years, the global situation of mosquito-borne diseases has become increasingly severe with accelerated global urbanization and a growing population. According to the latest report of the World Health Organization (WHO), vector-borne diseases account for more than 17% of all infectious diseases and cause more than 700,000 deaths annually (*1*). Approximately 80% of the global population is at risk of contracting these diseases, making them a persistent public health problem (*2*). The two main types of mosquito-borne diseases currently prevalent are viral and parasitic diseases. Taking several priority mosquito-borne diseases as examples: in terms of vaccine development, no vaccines have been developed or are still in the experimental stage for chikungunya fever (*3*) and malaria (*4*). It is worth mentioning that the R21 malaria vaccine has shown excellent clinical efficacy and is expected to produce 100 million doses in 2024 and up to 200 million doses per year thereafter, which may outstrip demand in Africa in the future (*5*). The vaccine for yellow fever (*6*) has been developed but is not widely available in poorer parts of the world. Dengue fever has only two vaccines commercially available: Dengvaxia for those with a previous history of dengue and TAK-003 (*7*), which was approved by the WHO in 2023 for use in children aged 6–16 years in highly endemic areas. Butantan-DV (*8*), which will complete a five-year trial at the end of 2024, is not commercially available. In terms of endemic regions, dengue fever is endemic in 129 countries, with Asia accounting for nearly 70% of the global dengue case burden (*8*). Yellow fever has irregular outbreaks in Africa and the Americas (*6*), and chikungunya fever is currently present in more than 100 countries or territories around the globe, causing about 1 million infections per year (*9*). During the COVID-19 pandemic, malaria caused 63,000 deaths (*8*). Additionally, resistance to antimalarials is increasing, and a new generation of antimalarials and vaccines is urgently needed (*10*).

Among the malaria control measures already in place, long-lasting insecticidal nets (LLINs) (*11*) and indoor residual spraying (IRS) (*12*) are most commonly used. The recent COVID-19 pandemic has created a need for the R&D of new control tools, especially those that are less labor-intensive, simple, and effective to implement (*13*). In2Care® EaveTubes (ETs) (*13*) are inexpensive, innovative, and resistant vector control products that use heat and odor generated by natural air currents in ventilation ducts located under the eaves of a house to attract mosquitoes to insecticide-treated bed nets inside the ducts. New mosquito control methods are also emerging. Genetic sequencing methods can be used to control mosquito-borne diseases (*14*), by predicting the transmission routes of viruses carried by mosquitoes and the genetic characteristics of mosquitoes to enhance species surveillance. Ivermectin (*15*) is another potential tool, with an anti-mosquito effect in clinical trials that far exceeded *in vitro* laboratory experiment predictions (*16*). Additionally, gene-driven technology utilizing *Wolbachia* has been applied in mosquito population suppression and modification (*17*) and appears to have some success; however, the implementation of this approach still requires long-term field experiments.

Global Mosquito Control Strategies and Challenges

Integrated Management

The strong adaptability of mosquitoes reduces the effectiveness of single vector control measures, contributing to the increasing prevalence of mosquito-borne diseases such as malaria, dengue fever, and yellow fever (*18*). Consequently, the WHO proposed the concept of integrated management in 2004 (*19*). Currently, integrated management is primarily implemented through two major aspects: technology and advocacy. Technological approaches include the timely diagnosis of mosquito-borne diseases (*20*), improved entomological testing (*21*), practical new mosquito traps for surveillance, the use of geographic information systems (GIS) for surveillance (*22*), and the use of new technologies to control mosquitoes and prevent transmission (e.g., deciphering the vectorial capacity of local mosquito populations and releasing improved mosquitoes) (*23*). Advocacy-level approaches include social mobilization, multi-sectoral joint mosquito control, and revision of mosquito control-related laws (*24*). However, the implementation of integrated management faces several challenges, such as mosquito control and ecological adaptability, uneven resources and capacity in different areas, and varying infrastructures and backgrounds of communities, necessitating time for comprehensive promotion (*25*).

Sustainable Mosquito Control

The sustainable mosquito vector control strategy was first mentioned in the WHO's Global Technical Strategy for Malaria 2016–2030 (*19*), and various countries have since taken different measures to implement this strategy.

In China, Qiyong Liu proposed the "sustainable vector strategy" (*26*), and academician Jianguo Xu suggested the "reverse pathogenesis" approach (*27*). The concept of "sustainable control" is characterized by health, economic, and ecological considerations, with multi-sectoral cooperation in vector biomonitoring, disease risk assessment, and control planning based on monitoring results, followed by a call for universal participation. "Reverse pathogenesis" aims to establish a forward-looking, proactive defense plan and joint prevention of major infectious diseases (*28*).

Policies adopted abroad primarily target both humans and mosquito vectors. Human-focused measures, known as human-mosquito interaction-social mobilization (*29*), emphasize identifying viruses with the potential for international transmission (*30*). Human-mosquito interaction is facilitated through online platforms, such as mobile communication technology and digital platforms, to share insect data (*31*). This approach broadens participation in mosquito vector prevention and control efforts. Subsequent offline mosquito disease prevention and control counseling workshops (*32*) further enhance residents' interest in and knowledge of mosquito vector control. Mosquito-targeted measures include utilizing biopesticides (*33*), employing insect sterility techniques (*34*) to genetically modify mosquitoes for post-release purposes, and developing artificial liquid diets without blood (*35*). These biological control methods offer a more environmentally friendly approach to mosquito control without jeopardizing non-target beneficial insect populations.

However, implementing these measures still requires time and effort because many communities are strongly skeptical about the purpose of releasing genetically modified mosquitoes and are concerned about potential negative impacts (*36*). Therefore, human-mosquito interactions require greater involvement from local communities and other stakeholders (*36*). Although genetically modified mosquitoes can help control mosquito-borne diseases such as malaria, they are not yet globally available (*37*). Additionally, while many methods effectively target parasites or viruses in mosquitoes, they can also disrupt or alter mosquito physiology, leading to changes in longevity, reproduction, and immunity (*38*). Therefore, the robustness and durability of transgenics remain debatable (*25*). Currently, some countries or regions also face dilemmas in adopting sustainable mosquito vector control measures (*39*), such as a lack of funding (*40*) and insufficient local expertise in mosquito species identification (*29*), leading to uneven global progress in sustainable mosquito vector control.

Global Vector Control Response 2017–2030

The WHO issued the Global Vector Control

Response 2017–2030 (GVCR) (*41*) on 2 October 2017 to combat vectors and vector-borne diseases (VBDs). By 2030, the GVCR aims to reduce mortality caused by VBDs by at least 75% and case incidence by at least 60% compared to 2016 levels, as well as to prevent VBD epidemics globally. Its key measures — strengthening inter- and intra-sectoral action and collaboration, engaging and mobilizing communities, enhancing vector surveillance, and scaling up and integrating tools and approaches — are comprehensively reflected in the integrated governance and sustainable control strategies of each country discussed above.

One Health Concept

One Health (OH) is an integrated, unifying approach to human and animal health, environmental health, food safety, and agricultural production (*42*), and its main applications in the field of mosquito-borne diseases are diagnostics for human treatment and mosquito diagnostics for vector control, which constitute two aspects of a broad and integrated ecosystem (*43*). A recent WHO article emphasizes the need to prioritize the inclusion of OH in strategic planning on the international political agenda (*44*), underscoring the importance of the OH concept.

Strategies for the Prevention and Control of Mosquito-borne Diseases in China, Focusing on Mosquito-free Villages

Vector control is a priority of the patriotic health campaign because it can effectively reduce disease spread, improve quality of life, and enhance living environments (*45*). In 2016, Zhejiang Province pioneered the development of "Mosquito-Free Villages" to address the persistence of mosquito-borne diseases (*46*–*47*).

The core concept of the Mosquito-Free Village is sustainable breeding ground control, with the innovation of integrating health into the government's "Ten Million Project", also known as "Beautiful Village Development" (*48*). For example, in Pujiang County (*49*) and Qingtian County (*50*), two demonstration counties, mosquito trapping lamps and *BI* were used in Pujiang County (*51*). In Qingtian County, the larval mosquito suction tube method and the double-layer stacked tent method were used for mosquito surveillance, transforming the rural ecological environment. Qingtian County also used a combination of government promotion and the introduction of the Patriotic Health Campaign Committee Office (PHCCO) to increase public recognition of Mosquito-Free Village construction. This was achieved through Party Day themes to increase the publicity of Mosquito-Free Village branding and adopt a low-cost and effective method to create a path toward environmental, mosquito vector disease, and human health improvement.

The corresponding construction standards have been issued and are available as models for other regions. On December 27, 2019, the local standard "Mosquito-Free Village" (DB3311/T 122-2019) was introduced, and on February 1, 2024, after continuous improvement and innovation, the group standard (T/ZJPCA 001-2024) "Guidelines for Sustainable Control of Countryside Vector Organisms — Four Pests" was officially released and implemented. Mosquito-Free Villages were subsequently promoted in all counties of Zhejiang Province; in Changsha, Hunan Province, in 2022; and in Xiangfeng Village, Fuling, Chongqing, in July 2023, marking the first pilot in Southwest China. These examples demonstrate that Mosquito-Free Villages are a cost-effective environmental remediation practice for sustainable mosquito vector control and a curative measure for realizing the WHO 2017–2030 strategy, which can be replicated and promoted. While the primary economic benefits of Mosquito-Free Villages vary, China is also conducting small-scale pilot programs using the *Wolbachia* mosquito sterilization method, with the expectation of national promotion in the future (*52*).

CONCLUSION

In short, mosquito control requires sustained efforts with three specific measures. First, each region should strengthen its monitoring system, train monitoring technicians, and establish a platform for sharing monitoring information to facilitate integrated early warning. Second, research should continue in the direction of biotechnology for mosquito control. Third, integrated environment-mosquito vector control should be carried out under the OH concept, as reflected in the construction of mosquito-free villages in China. With "mosquito-free" becoming the general direction and ultimate goal of prevention and control, it is the responsibility of every country to achieve a global "mosquito-free" world, using the goals of the "2017–2030 Global Vector Control Response" as a blueprint.

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