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Malaria Elimination Strategies: Lessons from Past Successes

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ABSTRACT

Malaria remains one of the most significant public health challenges worldwide, with billions of people at risk and disproportionate impacts on children under five and pregnant women in sub-Saharan Africa. While global interventions have reduced morbidity and mortality substantially over the past two decades, the persistence of transmission underscores the need for renewed elimination efforts. This paper examines lessons from past malaria elimination campaigns, focusing on vector control, chemoprevention, surveillance, and community engagement. Case studies from Sri Lanka, Morocco, and the Americas demonstrate that tailored strategies, integrated interventions, and strong political commitment are critical to success. These findings emphasize that elimination requires sustained investment, robust health systems, and local ownership. The lessons derived from historical and contemporary experiences provide a framework for guiding current and future efforts to achieve malaria elimination globally.

Keywords: Malaria elimination**,** Vector control**,** Chemoprevention**,** Surveillance, and Community engagement.

INTRODUCTION

Malaria elimination has become a priority for national governments and international organizations [1]. Solutions for strengthening operational strategies must build upon lessons learned from past nationwide elimination campaigns [2]. For as far back as records exist, malaria has been humanity's greatest scourge, known even in the Bible as the "fiery serpents" sent by God in punishment [1,2]. Research into the history and epidemiology of malaria is critical to determining what interventions are needed to control this disease because the strategies that historically have been successful for controlling and eliminating the disease have been highly dependent on the unique aspects of the regional or local malaria epidemiology, rather than on some universal approach [1]. Today the World Health Organization (WHO) estimates that there were approximately 247 million cases in 2021, but with the widespread and highly increased investments and interventions in the years following the 2007 launch of the globally endorsed Roll Back Malaria Partnership, the number of deaths fell markedly from an estimated 896,000 in 2000 to 619,000 in 2021, and the proportion of the weight of disease caused by malaria has fallen accordingly [2]. Despite this decline, malaria remains one of the world's most important diseases and a global health and development priority [3].

Global Burden of Malaria

Approximately three billion people remain at risk of contracting malaria globally [2]. In 2012, an estimated 207 million cases occurred worldwide, resulting in 627,000 deaths, the consequences of which are borne most heavily across the poorest nations of the world [2]. Malaria's mortality burden falls primarily upon young children (under five years of age) and women during pregnancy. The World Health Organization (WHO) African region accounts for 80% of malaria cases and 90% of malaria deaths worldwide [1, 6]. The countries contributing most to this burden remain concentrated in sub-Saharan Africa, with Nigeria and the Democratic Republic of Congo accounting for approximately 40% of the total worldwide. Malaria transmission also occurs across much of Asia, South America, and parts of the Middle East and Oceania. A further quarter of the world's population remains at risk of Plasmodium vivax malaria, where an additional 13 million cases were estimated in 2012 [1]. Around 500

million clinical cases of P. vivax were estimated to occur annually worldwide during the early part of the 20th century. Of those initially exposed to the parasite, 10–60% may experience multiple clinical episodes that can last for years and cause considerable morbidity and mortality. In 2013, the global economic cost of malaria illness and death was estimated at US$12 billion, a figure that rises to US$35 billion if regions with unstable or low transmission are included [2, 3]. Although mortality during clinical episodes affects mainly young children and pregnant women, the costs of malaria illness extend well beyond the health sector. Lost earnings and household expenditure on treatment represent a major economic burden to countries and families, and workdays are lost during recovery periods [5, 8]. Tax revenues decline owing to reduced productivity, and the expense of prevention and treatment does not spare even the wealthy. The rapid advance of malaria resurgence during the 1980s and 1990s reinforced the need to account for the broader economic and social burden of the disease [17].

Key Malaria Elimination Strategies

Three key methods essential for reducing the burden of malaria are in widespread use: vector control, chemoprevention, and surveillance [1, 3]. Vector-control measures, founded principally on the use of long-lasting insecticidal nets and indoor residual spraying, have been the cornerstone of malaria control programmes [6, 9]. Chemoprevention applied in different ways for high-risk groups preventive treatment in pregnancy, seasonal malaria chemoprevention in children in areas of highly seasonal transmission, and intermittent preventive treatment in infancy, provides wide-ranging protection [4, 9]. Surveillance can also be used proactively, either to target vector-control interventions or for active case detection and, together with an appropriate programme response, becomes the basis of a malaria-elimination programme [1]. Wide cross-sectional surveys (including serological assessments) and mass drug administration increasingly limit the parasite reservoir in an area and can also be part of an elimination programme. Given the long history of malaria control, a rich body of programme experience and supportive materials is available. In keeping with earlier efforts to identify the practical lessons that may be derived from past malaria-elimination initiatives [2], a review of three successful elimination efforts in Sri Lanka, Morocco, and the states of the Americas provides a means to elucidate the contribution of different strategies [22]. Each of these initiatives eliminated malaria after 1945, in diverse ecological and health-infrastructure settings, and under very different external conditions. These case studies enable an appraisal of the principal elements of contemporary malaria-control and elimination in real-world programme settings [20, 21].

Vector Control Measures

Vector control is fundamental to malaria-elimination efforts. Large-scale indoor residual spraying (IRS) has historically been the most effective vector control intervention [1]. During elimination programmes, vector control is targeted at sites of transmission and requires a different approach to routine control programmes [1, 4]. Geographic risk maps prepared through geostatistical analysis of human cases provide the starting point for vector-surveillance activities, allowing the prioritisation of areas for entomological surveillance and measurement of population-level insecticide resistance [5, 6]. Resistance to chemical agents that target the vector is a major current threat to elimination and requires regular surveillance with molecular and bio-assay techniques. Resistance posed a major problem to elimination campaigns in South Africa and Sudan, where it is widely believed to have caused resurgence [7, 8]. Most programmes concentrate vector-control efforts on indoor-biting vectors, using IRS as an effective and economic means of control. Complete cessation of transmission is unlikely, however, unless interventions also target outdoor-biting and outdoor-resting vectors (e.g., through larval control and insecticide-treated livestock) [10]. The relative importance of these vectors and the contribution they make to transmission remain unclear; further work is required to develop effective surveillance approaches and targeted control measures [13].

Chemoprevention

The potential of chemoprevention to protect populations from malaria has garnered substantial interest during phases of vaccine scarcity [4]. Effective delivery of chemopreventive interventions involves substantial logistical complexity, necessitating recurrent interactions with large cohorts to attain and maintain high coverage rates; replacement of existing regimens with fully efficacious drug combinations is imperative. Chemoprevention constitutes a vital instrument in efforts to counter recent stagnation in malaria control. Appropriate settings for chemopreventive application depend upon transmission dynamics and other epidemiological factors; empirical data and transmission models have been employed to inform critical decisions regarding timing and implementation of such interventions [4, 5]. The principal WHO-endorsed chemoprevention strategies include intermittent preventive treatment in pregnancy (IPTp), seasonal malaria chemoprevention (SMC) for children under 5 years of age, intermittent preventive treatment in infants (IPTi), and mass drug administration (MDA) [5]. Development of resistance constitutes a pervasive concern, yet strategic deployment of multiple approaches can mitigate this risk and facilitate inclusive protection across diverse populations.

Surveillance and Monitoring

Monitoring, evaluation, and surveillance are core interventions across the malaria-elimination continuum [6, 7]. Considering that the value of such activities resides in the timely and appropriate use of obtained information to ultimately guide operational decisions to target program effort and resource allocation, malaria-elimination surveillance systems also need to be responsive to the epidemiological situation and contextual setting in which they are implemented [6]. Countries approaching elimination need to improve system coverage by extending access to remote communities; expand reporting from private-sector providers; transition from aggregate to case-based reporting for individual-level data capture; and increase incorporation of additional sources of information [7]. Enhancing data quality and ensuring accessibility, integration, and higher-level data visualization, while concurrently promoting routine data-use practices, can substantially improve the value of information generated by surveillance systems [15]. Incorporation of these elements will enable malaria teams to target interventions and guide program activities with maximum operational efficiency at all transmission stages [13]. For countries with remaining foci, reorientation and reorganization of surveillance systems will be essential to ensure timely identification and response to active transmission at very low incidence levels. Once local elimination has been achieved, efforts must maintain vigilance to ensure rapid detection of subsequent malaria importation, reintroduction, or resurgence and to identify possible outbreaks [16]. Advances in information and communication technologies provide additional opportunities to improve surveillance-system performance across malaria-elimination scenarios by increasing utilization of both active and passive case-detection methods, facilitating automatic triggering of alerts, and easing the communication of information to decision-makers. Integration of malaria surveillance activities within broader public-health information systems, as recently achieved by Sri Lanka, can further increase the overall impact of national surveillance efforts in elimination contexts and also promote sustainable capacity in the long term [15].

Community Engagement

Community engagement, defined by the Global Health Group as "the process of working collaboratively with groups of people to address issues affecting their well-being", represents a critical component of malaria-elimination campaigns [8]. Complex factors and high heterogeneity of transmission patterns have precluded a universal approach to community engagement; continued malaria transmission in many endemic countries persists mainly in border areas with difficult access and among mobile populations that are hard to reach through standard health-service delivery [2, 10]. In such settings, conventional interventions require the endorsement and active participation of communities in order to attain the greatest impact [13, 18]. Likewise, malaria-elimination efforts also rely extensively on community engagement because they generally necessitate near-universal, high coverage and uptake of a wide assortment of interventions and active surveillance to rapidly identify and treat any remaining malaria cases [2, 9]. Furthermore, providing continued support for malaria-control activities in low-transmission settings entails overcoming a paradox of diminishing motivation to sustain those activities once transmission declines[7, 8]. According to the WHO, community engagement represents one of the five critical properties of a well-functioning national malaria programme. Community engagement has been integrated seamlessly into national programmes in every country where elimination has been successfully achieved; it is also a fundamental pillar of the 2017–2030 Global Technical Strategy for Malaria [5, 8]. Community engagement activities present a useful entry point for tapping communities and other related social groups in order to reconsider the behavioural and social aspects that influence health and development in any given setting, both for malaria and beyond. Malaria-elimination research, monitoring and evaluation, and implementation can all potentially benefit from concerted efforts to strengthen community engagement within the national programme and its related health and development sectors [20]. Between 2000 and 2015, seventeen countries successfully eliminated malaria, and a further ten countries were expected to do so by 2020. However, funding for malaria control has remained relatively stable, and around 219 million cases were reported in 2017[2, 19]. In countries that have decreased the malaria burden substantially, cases tend to cluster into small geographical areas and among high-risk subpopulations [21, 22]. Existing methods of vector control and case management remain effective, as do malaria medicines, diagnostics, vaccines, and insecticides. Nonetheless, such interventions only work if they are accessible, acceptable to the local population, and properly used within communities with the greatest need [15, 18]. Given that challenges to malaria elimination are highly site-specific, no single approach to engaging communities can adequately address the wide range of circumstances where intervention coverage remains low[1, 3, 7]. The need for local solutions is now widely recognized in the literature, with community engagement emerging as a critical means of ensuring that solutions reflect local realities. Community activities, therefore, constitute a vital entry point: the use of community health workers for case management, surveillance, vector control, and health education already represents the most common form of community engagement within

malaria programmes globally[9, 21]. The potential exists to increase the role of community engagement further, and to work across scales to reorient how communities contribute to designing, implementing, and monitoring activities. Lessons derived from other health and development programmes offer valuable insights regarding modalities and methods to achieve these goals [22].

Case Studies of Successful Malaria Elimination

Malaria elimination has been successfully achieved in Sri Lanka, Morocco, the Caribbean, and Central and South America. Nations that have achieved elimination largely adopted highly programmatic approaches characterized by strong case management, robust surveillance programs, well-managed vector control, and effective addressing of population movement [1]. The GMEP provides an important reference point for understanding the operational strategies needed to interrupt transmission. In the late 1990s and early 2000s, a global rebounding of infections accompanied by rising drug and insecticide resistance galvanized international commitment to renewed efforts to reduce malaria [3]. Attention initially focused on regions including much of sub-Saharan Africa, parts of Southeast Asia, and Latin America, where the burden of disease was highest and transmission most intense. Initially conceived as a purely pre-elimination exercise, the Abuja Declaration of 2000 and the subsequent Global Roll Back Malaria (RBM) Programme shifted towards a longer-term eradication research agenda that would take more than two decades to implement[2, 9]. International support is provided chiefly through the World Health Organization (WHO), the support agency responsible for certification of national elimination. Regional offices within the WHO oversee plans to achieve elimination with further support from periodic external evaluations. The Global Malaria Programme recently revised its Global Technical Strategy and Framework for Malaria Elimination, specifying policies and core interventions for the eventual purpose of eradicating the disease globally. WHO also coordinates research efforts through the Malaria Policy Advisory Committee and supports product development partnerships such as the Innovative Vector Control Consortium and Medicines for Malaria Venture [2]. The periods in which malaria was eliminated from many countries were associated with a complex mixture of improved health systems (including increased availability and access to effective treatment), socioeconomic development, and targeted programme activities, including control of vector breeding sites, widespread indoor residual spraying with insecticides, and mass drug administration. Case studies emphasize the central role of carefully managed, well-governed, national malaria elimination programmes and their ability to translate broad politico-economic health gains into concrete strategies to interrupt malaria transmission [2].

Malaria Elimination in Sri Lanka

Sri Lanka stands out as an exceptional case where malaria was eliminated in a conflict-affected setting [16]. The country aims to achieve elimination by the end of 2014 through key activities including case surveillance, notification, radical cure, rapid response, and management of importation [7, 15]. Identification and treatment of imported infections must continue, especially as rising tourism and ferry services from India increase the risk of reintroduction [1, 5]. Securing long-term, sustainable funding is essential, particularly in the aftermath of recent reductions in support from global funding sources. Historical experience during the 1960s illustrates the consequences of funding setbacks that contributed to malaria resurgence. High-quality cost estimates and comprehensive cost-benefit analyses can further justify the need for sustained financing in low-endemic and elimination contexts [9]. The World Health Assembly (WHA) resolution of 2015 calls for elimination in 35 countries, targeting a 90% + decrease in global malaria incidence and mortality by 2030. Sri Lanka secured World Health Organization certification of elimination in 2016 [20, 22]. Throughout much of this campaign, the country was entrenched in a civil war, which served to heighten the public health impact and complexity of elimination efforts. Malaria epidemics were recurrent during the early 1900s. The 1986 outbreak coincided with the 1983–2009 war, which was largely confined to the north-eastern portion of the island. Conflict zones maintained numerous stagnant pools of water, rendering them ideal environments for vector breeding; in 1996, 41% of cases emanated from these areas [1, 14]. Despite these challenges, a substantial reduction was effected, culminating in a 70% decrease in cases between 2000 and 2001. The experience provides key lessons for other endemic countries that face ongoing or potential conflict [3, 17]. Contemporary analysis situates this success alongside other elimination operations to elucidate the foundation of strategies and the contribution of these approaches to countries' broader historical trajectories [20, 21, 22]. The investigation utilizes interviews with 31 experts from international organizations, government agencies, academia, and the military, supplemented by documentary analysis that chronicles the multifaceted nature of Sri Lanka's malaria elimination [10]

Malaria Control in Morocco

Malaria control in Morocco involves efforts towards elimination [1, 15]. The WHO's 2007 report highlights global malaria strategies, including active case detection based on models from countries like Brazil. Studies indicate progress in regions such as the Arabian Peninsula, where malaria elimination efforts between 1960 and

2010 have reduced transmission. In Greece, malaria was reported from 1975 to 2010, showing successful control, while in Tanzania, district-level strategies have been implemented [12]. Asia-Pacific countries have made significant strides toward elimination, with tailored strategies to target imported malaria via social networks. Sensitive diagnostic tools like loop-mediated isothermal amplification are used in endemic areas for early detection. Data management systems and cluster detection techniques guide targeted interventions. The WHO's manual on malaria elimination provides guidance for low and moderate-endemic countries [11]. Lessons from South Africa's active case detection highlight the importance of community-based approaches. Historical re-emergence and reconquest of malaria in regions like India and Madagascar emphasize challenges faced in maintaining elimination status. Overall, malaria control in Morocco is part of a broader regional and global effort to move towards eradication [11].

Success in the Americas

Progress toward malaria elimination in the Americas owes much to lessons from early malaria campaigns, gains in reducing infant mortality, growing international financial support, and a solid foundational knowledge of malaria transmission and control [16, 19]. In the 1950s, as the global malaria elimination campaign gained momentum, Colombia, Venezuela, and Haiti had already dramatically curtailed transmission, stymied only by the spread of DDT resistance [3, 12, 13]. Early achievements proved that elimination could succeed over large geographic areas, in heterogeneous transmission foci, and without suppressing biological vectors or attaining total domestic housing. From 1947 through 1960, about one million cases per year were reported in the Americas; by 2010, cases had fallen to 250,000 [1]. Across the region, official malaria deaths declined from over 150,000 to just 50 in 2010 [3]. Before the 1950s, malaria elimination had not been achieved anywhere; by 2010, it was within reach throughout the region [12].

Challenges to Malaria Elimination

Challenges to Malaria Elimination. Overcoming the acknowledged challenges of drug and insecticide resistance is a matter of immediate global concern. Client adherence, substandard drugs, counterfeit drugs, and inappropriate drug use hasten the development of resistance [2]. The geographic extent of resistance has broadened to virtually all the antimalarials that have been deployed at scale, severely limiting their usefulness. Recent advances in the formulation of single-dose cures may represent the kind of transformational innovation needed to improve adherence and reduce the risk of resistance [2, 17]. Widespread resistance to insecticides also hampers efforts to use insecticidal approaches, particularly when resistance is combined with the behavioral avoidance associated with residual transmission. In addition to these somewhat daunting technical challenges, the malariologists' toolkit must be expanded to address critical limitations associated with the available intervention options. Restrictions imposed by cost or operational practicality are critical [16]. As an example, because the vast majority of interventions, whether containing pharmaceuticals, insecticides, bednets, or mass blood screening, require some form of well-trained human resource to distribute or deploy them, the available supply of skilled and supervised personnel becomes an immediate bottleneck in many endemic countries [2, 17]. Although commodity costs continue to be highlighted as a major challenge, the underlying reality is that better diagnostics, more effective drugs, and more lasting vector control measures would all lead to far bigger dividends for each programmatic dollar than cheaper but inferior products. Commodity costs become a challenge only when better options are not available [1].

Drug Resistance

Drug resistance is a major obstacle to the elimination of malaria. Resistance of Plasmodium falciparum to chloroquine began spreading in the 1960s and 1970s. As a result, chloroquine was replaced by sulfadoxine–pyrimethamine (SP) in the 1990s, which was used in both treatment schemes and preventive measures (e.g., intermittent presumptive therapy for malaria in pregnancy) [1, 22]. After the millennium, both chloroquine and SP were replaced with artemisinin-based combination therapies (ACTs) as first-line antimalarial treatment in virtually all malaria-endemic countries. Distribution and spread of mutants responsible for artemisinin resistance have been tracked in real time; mutant PfKelch13 alleles have appeared multiple times independently [13]. Parasites have consequently developed resistance to nearly every available drug, but ACTs remain effective in most endemic regions and are somewhat more resilient against the evolution of resistance than previous drugs [14]. This resilience is maintained by a combination of factors: (a) the therapy includes drugs with different modes of action, which makes it difficult for parasites to acquire cross-resistance; (b) the partner drug has a longer half-life than artemisinin and kills residual parasites after artemisinin has been cleared from the circulation; (c) incomplete treatment generally increases selection against resistance, because the drug with the longer half-life remains present when the drug with the shorter half-life has been cleared and imposes its selective restrictions alone[1, 17]. Nevertheless, resistance to both parts of the combination therapy has evolved for previous

artemisinin-based combinations [13, 14]. The global spread of artemisinin resistance represents a direct threat to malaria control and elimination efforts.

Insecticide Resistance

Pyrethroids constitute the major class of insecticides employed against the malaria vector. Insecticide resistance is decreasing the efficacy of this vector-control intervention [15]. Pyrethroids are utilised in long-lasting insecticide-treated bednets and indoor residual spraying to combat malaria, but resistance undermines operations and serves as a major barrier to progress [5, 19]. Vector-control programmes supply public-health protection against multiple vector-borne diseases, not only malaria, and insecticide resistance constitutes a considerable threat to the prevention of these pathogens [20]. Mosquito populations are resistant to at least one insecticide (from any chemical class) in 61 countries, and to all approved compounds in at least one country. Resistance remains patchy in time and space, and heterogeneous within locations [21, 22]. The degree to which long-lasting insecticide-treated bednets or indoor residual spraying will lose epidemiological efficacy once phenotypic resistance emerges remains the major uncertainty, and the scientific question of greatest importance. Resistance management strategies have been proposed, but a robust evidence base for policy remains lacking [19, 22].

Funding and Resource Allocation

The effective allocation of funding and resources is essential to the implementation of targeted elimination strategies [1, 3]. Techniques that enable the efficient use of limited means can help programs reach their malaria goals. Historically, funding allocations for malaria initiatives have been primarily categorized into those focusing on elimination and those dedicated to broader control measures [1, 18, 22]. Estimates from 2017 indicate a global commitment of approximately US$2.7 billion exclusively towards elimination activities. When examining financial distributions, allocations differ considerably based on the economic status of regions [12, 17]. Middle-income countries predominantly channel resources towards either control efforts or elimination interventions such as surveillance, while low-income countries, heavily reliant on donors, allocate the majority of their budgets to core interventions like vector control and treatment [16]. The cross-case analysis of nine successful elimination programs highlights the importance of sustained financial and human capital. Stable and predictable funding streams enabled the maintenance of robust surveillance and vector control operations, even in challenging contexts such as conflict zones [2]. Conversely, the temporary reduction or cessation of resources often precipitated resurgence events, underscoring the fragility of gains in the absence of continued support [13]. Some countries that depended exclusively on domestic financing encountered specific challenges but benefited from greater programmatic consistency compared to those reliant on volatile external assistance. For instance, Mauritius responded to a resurgence epidemic by allocating more than US$2 per capita toward malaria activities despite zero indigenous transmission, thereby reinforcing efforts to prevent further outbreaks [1, 2, 19].

Innovative Approaches to Malaria Control

Innovative approaches are emerging in malaria control due to the increasing allure of disease elimination. Progress in developing a transmission-blocking vaccine offers a path to permanently interrupt transmission; such vaccines are progressing through clinical trials [9, 11]. The introduction of new insecticides for indoor residual spraying could delay or prevent resistance patterns from reversing prior gains. Strategies for administering anti-malarial medications to entire populations could exert transmission pressure or sustain suppression in areas lacking health infrastructure [12]. Genetic modification of vectors holds promise for unbalancing the vector-parasite equilibrium. Although these methods could be transformative, they remain distant prospects [16]. Further diagnostic, therapeutic, and preventive innovations have the potential to accelerate elimination, yet pragmatic use of existing tools already supplies a comprehensive foundation for strategy development and implementation [17].

Genetic Modification of Mosquitoes

Over the past 20 years, the optimization of stable transformation of Anopheles mosquitoes has enabled the introduction and maintenance of foreign genes that potentially reduce transmission of human malaria [13]. Various genotypes that disrupt parasite development in mosquitoes have been shown to spread in populations when linked to "driver" genes capable of propagating themselves through the population. Although such genotypes have already been introduced into several non-vector species of Anopheles [18], their use to date remains strictly laboratory-bound. The field has yet to produce a major deployment of transgenic mosquitoes, in spite of decades of work and the joint efforts of numerous teams worldwide [19]. Successful control programs involving the replacement or modification of insect populations capable of transmitting disease would constitute a major breakthrough in public health. Significant opportunities exist for further discussion and research regarding the necessary accompanying measures accompanying these programs [20].

Vaccination Efforts

While a highly effective malaria vaccine remains elusive, vaccination efforts are nonetheless integral to ongoing control and elimination strategies [13, 15]. The RTS, S/AS01 vaccine, the only malaria vaccine approved for widespread use, has undergone broad implementation across several countries. Demonstrating approximately 30–50% efficacy in young children, RTS, S significantly lowers the incidence of clinical malaria, thereby reducing strains on health systems [21]. Additional vaccine candidates targeting various stages of the Plasmodium life cycle or harnessing genetically modified Plasmodium sporozoites are currently in preclinical and clinical development [14]. Widespread distribution of an optimal malaria vaccine would constitute a major catalyst for advancing elimination efforts. Vaccines effective at interrupting transmission will play an especially critical role, together with other control tools, in the final stages of elimination and in maintaining a malaria-free status post-elimination[15,16].

Role of International Organizations

No disease has influenced the evolution and development of man more than malaria [13, 17]. The universal distribution of the disease in the past, the extreme vulnerability of non-immune populations, the severe morbidity and mortality resulting from the disease, especially among children and its damaging effect on the economy of malaria-endemic countries are some of the factors that have contributed towards the endemicity of the disease in the majority of the present day tropical and sub-tropical countries [2, 13]. The burden of malaria today is reflected in the mortality and morbidity caused by the disease, the economy of countries in which the disease is endemic, and the amount of resources consumed for its control and prevention [11, 15]. Malaria elimination is an epidemiological concept denoting zero malaria parasite incidences. Currently, malaria is endemic in 97 countries and more than 3·2 billion people are at risk, but only 38 of these countries have set an official malaria elimination on their agenda. History has shown that through sustained, coordinated efforts, malaria elimination is possible [19]. It has been successfully eliminated in a number of countries, such as Sri Lanka and Morocco. In Sri Lanka, the malaria elimination programme, launched in 1958, succeeded in the interruption of local malaria vector-borne transmission by 1963, without the use of mass drug administration. Malaria elimination has also been achieved in the North and South Americas [20].

World Health Organization Initiatives

World Health Organization (WHO) initiatives enable countries and regions to sustain gains in malaria control and move towards elimination [1]. By end-2015, the WHO Global Technical Strategy for Malaria called for the elimination of malaria from 35 countries by 2030 [2]. Established in 2016, the WHO Global Malaria Programme (GMP) works with partners and agencies such as Roll Back Malaria to pursue elimination and eradication [1, 3]. WHO maintains global standards and offers technical guidance and both policy and strategic advice [2, 6]. Operational strategies and a move to elimination surveillance for monitoring can be applied according to context and capacity [1]. WHO prohibits stockpiling insecticides for indoor residual spraying to help avoid degrading the effectiveness of key tools. Frameworks and tools guide action plans and implementation. The feasibility of malaria elimination at the regional, national, and local levels is assessed to inform national malaria plans and to mobilise partners [12]. Continued support for acquired immunity and clinical management remains a crucial component of national control programmes [6].

Partnerships and Collaborations

The importance of partnerships and collaborations in achieving malaria elimination cannot be overstated [1]. Such alliances enable combinations of technical and operational expertise, workforce strengthening, access to commodities and financial resources, and sharing of best practices and lessons learned. Collective action is therefore essential for enhancing efforts and extending impact [2]. National malaria programmes frequently engage in multisectoral collaboration, working with other government ministries, the private health sector, extractive industries, NGOs, faith-based organizations, and the private sector [12]. Bhutan and Cape Verde, for example, partner with ministries of Agriculture and Environment to address sites for mosquito larvae grazing; Namibia, Angola, the Philippines, and Sri Lanka collaborate with NGOs to support LLIN distribution [13]. In Ethiopia and Zambia, coordinated efforts with private health facilities help expand active case detection; programmes also coordinate with military, forestry, and mining establishments, as well as training institutions. Plantation and construction companies have allied with national programmes in Angola, the Philippines, Cambodia, Thailand, Timor Leste, the Solomon Islands, Vanuatu, and Malaysia to educate employees, establish clinics, train volunteers, and improve screening and reporting systems for migrant workers. Such partnerships have played vital roles in preventing resurgence, boosting coverage, and managing cross-border and migrant labour challenges [3, 18]. In the Ecuador–Peru border region, binational collaboration at the operational level proved fundamental to the elimination programme's success, fostering a trusting and open environment that

enabled flexibility, rapid response, innovation, resilience during crises, and ultimately a sustainable control effort. Alongside strong community involvement, an extensive microscopy network and ongoing local epidemiologic investigations were also identified as crucial strategies [22].

Lessons Learned from Past Successes

Identifying malaria elimination unfinished journeys presents a process that defines causes of failure, rectifies them, and effectively applies solutions [9]. Analysis of malaria epidemiology through history and the global burden of the disease, with consideration of available tools of prevention, treatment, diagnosis, and control, points to contemporary successful elimination situations that provide lessons for future analyses focused on the three most recent success stories: Sri Lanka, Morocco, and the countries of the Americas [7, 8]. Much has already been published by the World Health Organization (WHO) about the topic: key strategies of the Global Technical Strategy, the push for elimination through chemoprevention in pregnant women and in the first years of life, the importance of surveillance during preventive therapy, protection of migrant populations with preventive therapy directed to those from malaria-transmitting areas, critical challenges like drug and insecticide resistance, and the development of new tools including genetic modification of the anopheline vector and the RTS, S vaccine[5]. Indeed, the WHO programs and alliances are responsible for building the foundations of effective malaria elimination on a global scale, providing lessons learned and addressing the unfinished agenda. Notwithstanding, such key ideas and relationships can be checked for their application at the level of specific historical and contemporary successes [20, 22].

Importance of Sustained Efforts

Political commitment, sustained funding, community engagement, enabling policies and regulations, and the ability to anticipate threats are fundamental to supporting elimination efforts [1, 18]. A malaria programme with strong coordination and incentives, backed by good governance, remains the greatest determinant of progress towards elimination [3, 5]. Achieving elimination requires operational and financial tracking systems to monitor the scale and quality of implementation efforts. As elimination is achieved, the operational environment evolves, necessitating programme adaptations to manage new challenges. National malaria programmes must balance an evolving set of technical, operational, and even political challenges within their contexts, for which the capacity and skills required to manage will change accordingly[10, 22]. All these factors will influence success in implementing national strategies [2]. Until new tools and approaches become available, operational and financial tracking systems are needed to monitor the scale and quality of interventions, enabling programme adjustments in response to the evolving epidemiological context below the elimination target [1, 11].

Adaptability to Local Contexts

Collectively, case studies from Sri Lanka, Bhutan, and Sabah State in Malaysia illustrate the importance of adapting national malaria control strategies to specific epidemiological and socioeconomic contexts. In Sri Lanka, targeted interventions such as the shift from universal to focal indoor residual spraying (IRS) and the adoption of insecticide rotation in all districts addressed local patterns in transmission and resistance[1, 3,7]. Community engagement through Farmer Field Schools enhanced awareness of insecticide use, complementing the distribution of primaquine for radical cure and rapid diagnostic tests to mobile clinics [4, 9]. Bhutan's concerted emphasis on mapping, surveillance, and response capacities supported the timely identification and containment of residual transmission foci [2, 6]. In Sabah State, the training of primary health care volunteers facilitated active case detection, capturing 14% of blood slides; the subsequent broadening of surveillance and implementation of integrated vector management strategies were underpinned by explicit national directives. Across these examples, aligning programme components proactively with prevailing determinants of transmission effectively constrained residual malaria and accelerated progress towards elimination [2, 7].

Future Directions in Malaria Elimination

Global goals for malaria control, elimination, and eradication have evolved rapidly [1]. A global goal of malaria eradication by 2040 was recently proposed, and a new Global Technical Strategy for Malaria (GTS) was launched by WHO in 2015, with an elimination target of 35 countries by 2030. Many malaria programmes are considering or committing to elimination and working to integrate GTS and AIM principles into their strategies. Countries must ensure political commitment and funding and address major technical challenges such as drug and insecticide resistance [1, 16]. An overarching challenge at the national level is inadequate health system performance, including weak surveillance, poor diagnostic and treatment tools, supply chain issues, an unregulated private sector, weak monitoring and evaluation, and insufficient technical and human resources [1, 2, 15]. Ensuring that national programmes have personnel with appropriate management skills and tools is essential to achieving elimination and eradication [2]. Achieving malaria elimination requires innovative approaches and new tools that complement existing ones. Effective and affordable diagnostics capable of detecting subclinical infections and

distinguishing recrudescences from reinfections are needed [3]. Next-generation drugs must be developed to overcome parasite resistance and effectively clear subclinical infections and gametocytes to block transmission. Transmission-blocking vaccines can also play a critical role in reducing onward transmission. New vector control interventions are needed to tackle increasing insecticide resistance, affect outdoor biting vector species, and serve as a bridge to the implementation of genetic approaches. Understanding the best combinations, mixes, and deployment strategies for diagnostics, drugs, vaccines, and vector control remains an open question to accelerate elimination. Furthermore, research to identify measures that sustain elimination and prevent reintroduction is essential in areas where transmission has recently been halted [17]. Malaria elimination requires that countries maintain technical and financial commitment even when cases decline to low levels. Most countries considering elimination currently lack the surveillance systems needed to reach the 'last few' cases and will need to invest substantially in disease notification and data analysis. Success depends on regional commitment and the creation of an enabling environment supported by strong health systems, community participation, skilled human resources, sustainable financing, appropriate legal frameworks, and political stability [2, 3, 8]. Systematic reviews of the surveillance and response methods deployed and case studies from recently malaria-free countries should guide strategy refinement. Research to improve diagnosis, treatment, vector control, and methods for assessing elimination feasibility is needed [1]. Historical experiences from the Global Malaria Eradication Programme, especially in complex settings such as Africa and Asia, remain invaluable [1]. While earlier attempts employed a one-size-fits-all approach, high-endemic regions require flexible strategies adapted to local epidemiology. Achieving elimination is likely to depend on combining robust surveillance with tailored vector control, rather than a solely global eradication effort. New approaches, technologies, and mechanisms for sustainable financing are crucial for changing the malaria distribution and ultimately confronting worldwide eradication [1].

Research and Development

Despite progress since the 2015 Global Technical Strategy for malaria, several setbacks such as insufficient funding and the COVID-19 pandemic have slowed the decline of malaria burden, underscoring the need for new tools and approaches[1,2]. Research and development (R&D) for malaria eradication demand tools and strategies that complement existing interventions; priority activities depend on the stage of control or elimination [17]. WHO's R&D agenda supports the ambitious targets of the Global Technical Strategy through 2030. Changes in vector populations and behaviours require adaptation to maintain intervention effectiveness [1, 13]. At a glance, recent advances demonstrate the concerted gains in malaria commodities. Regarding diagnostics, rapid diagnostic tests (RDTs) are widely used, and new highly sensitive tools detect subclinical infections; combination tests differentiate Plasmodium falciparum from P. vivax, and non-invasive sampling emerges [18]. Drug R&D has enabled large-scale deployment of artemisinin-based combination therapies and renewed guidelines for mass drug administration; low-dose primaquine safely reduces transmission; new antimalarials and endectocides (occasional human treatments that kill mosquitoes) enter clinical development; a marker of artemisinin resistance has been identified. Vaccine development reached a milestone with the European Medicines Agency's positive opinion on the RTS, S vaccine, accompanied by a WHO recommendation; the vaccine development roadmap was updated; and new candidates have advanced into clinical trials [19].

Policy Recommendations

Past malaria-elimination successes provide an important foundation for future efforts. Comparative assessments of well-documented case studies highlight common elements that can facilitate elimination [1, 12]. Almost all elimination programmes begin by realigning national control strategies and identifying existing gaps. Because single interventions will be inadequate for elimination, a combination of vector-control measures, chemoprevention, active-case detection, rapid-response methods, and efficient surveillance systems must be employed and scaled up in previously malarious areas, with continued emphasis on health-system strengthening, partnerships, and strengthening of human resources. Sri Lanka reduced malaria incidence to very low levels before reinforcement measures halted transmission [1, 14]. The Moroccan National Malaria Programme, despite an incomplete knowledge of local epidemiology, employed a well-managed training and education campaign, together with collaborative partnerships (including health and non-health sectors as well as communities) and well-informed programme management to interrupt transmission. In 2011, all countries of the Americas (except Venezuela and Guyana) were certified malaria-free by the WHO. Although the regional achievement reflected engagement at multiple levels, including political, financial, and technical, it also required adaptive programme management and uses a multipronged elimination strategy [19]. Local elimination programmes typically do not have the scope or resources to complete formal feasibility studies; the decision to pursue elimination is often based on national (or regional) political mandate rather than technical advice. Periods of rapidly declining incidence often spur national drives toward elimination: as transmission decreases, fewer interventions are required to

contain each additional infection, and a sense of optimism ensues [20]. Malaria-eradication efforts flower spontaneously after periods of rapid decline as key stakeholders become mobilized. Before Zambia's National Malaria Strategic Plan (NMSP 2011–2015), identification and selection of specific elimination districts was a collaborative and iterative process involving the National Health Strategic Planning Unit, Ministry of Health, National Malaria Control Centre, and partners[21]. Following the development of the NMSP, maps were developed detailing intervention coverage and disease burden for each manageable administrative unit. Malaria prevention and control measures and existing levels of transmission were identified and assessed to select the most appropriate elimination phase (accelerate, pre-elimination, or elimination)[22]. Eliminations were generally limited to districts with an annual parasite incidence of less than 50 per 1,000 population; however, countries used diverse criteria and frameworks to identify elimination areas [1, 22].

CONCLUSION

The history of malaria control demonstrates that elimination is achievable when strategies are adapted to local epidemiological and social contexts. Successes in Sri Lanka, Morocco, and the Americas highlight the importance of integrated approaches that combine vector control, chemoprevention, and surveillance with strong community participation and government leadership. Sustained investment and vigilance are essential, particularly in the face of growing insecticide and drug resistance. As malaria transmission declines, maintaining motivation and funding becomes more challenging, yet these are precisely the conditions under which elimination must be secured. The lessons from past successes provide a blueprint for countries still burdened by malaria, offering practical guidance on how to strengthen health systems, engage communities, and ensure sustainable progress toward global eradication.

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