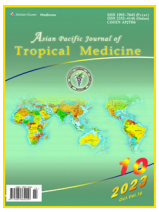

Perspective

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Malaria slide bank plays a crucial role in achieving and sustaining malaria elimination in India

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India's healthcare system continues to place the highest priority on the fight against malaria[1]. Malaria elimination program has received considerable attention from both the public and private sectors, resulting in a significant drop in malaria cases[2]. In 2022, a total of 176000 million cases of malaria were reported in India, in which *Plasmodium (P.) falciparum* has contributed 57.0% and 42.3% were *P. vivax* cases and limited cases of *P. malariae* and *P. ovale*. Microscopic examination is the gold standard diagnostic method (around 152 million blood smear examinations in 2022) to detect malaria in India[2]. However, several factors may affect the microscopy examination results, such as the quality of blood smear, staining, fixation, *etc*[3]. Malaria slide bank (MSB) is a collection of quality-controlled (QC) malaria-positive and malaria-negative slides that have been helpful in training and capacity building, quality control, monitoring, and research opportunities[4]. When India is on its path to eliminating malaria, the development of a MSB is a crucial asset for the nation when it comes to quality diagnosis. Following the recommendation of the World Health Organization (WHO) to develop a regional MSB[5]. ICMR-National Institute of Malaria Research, Delhi has recently launched India's first MSB, marking a significant milestone in the country's fight against malaria.

1. Establishing the malaria slide bank: Objectives and methodology

The establishment of MSB at ICMR-National Institute of Malaria Research has followed rigorous protocols to ensure it met international standards[5] (Figure 1). Blood samples were collected from malaria-positive patients in endemic areas of India, and both thick and thin blood smears were prepared using a fast-staining method with Giemsa stain[6]. QC slides were validated by WHO-certified level-1 microscopists. DNA extraction and PCR analysis were used to confirmed the species of malaria parasites. The slides meeting quality criteria underwent parasite counting, labeling, and storage. The MSB's stringent QC ensures accurate and reliable slides for microscopist training, benefiting malaria control efforts in India.

2. Challenges in malaria slide banking

Development of an MSB necessitates significant resources, such as funding, qualified personnel, laboratory apparatus, reagents and maintenance. These resources may be limited in areas where malaria is endemic, making it challenging to establish a slide bank[4]. The quality of prepared slides is critical for accurate diagnosis. Preparing high-quality slides requires a high level of technical expertise, and QC mechanisms must be in place to ensure that prepared slides meet the necessary standards and were stored correctly to maintain their quality. The Giemsa-stained smear is known to preserve red blood cells and malaria parasites for a longer period of time[7]. Factors such as temperature, humidity, and exposure to light can affect the quality of prepared slides. Antimalarial resistance is another serious concern that can lead to a change in the morphology of the malaria parasite[3]. The malaria parasite has a complex life cycle that involves several distinct stages, and the type of morphological changes can vary depending on the specific antimalarial drug and the level of resistance[3]. Therefore, by examining prepared slides from MSB, technical personnel and researchers can study the morphology of parasite at each stage of its life cycle, from the early ring stage to the mature trophozoite and schizont stages. There are other numerous operational and technical challenges in malaria microscopy quality assurance for routine checking of blood smear, such as human error, training, standardization, infrastructure, logistics, and so on[4]. Therefore, addressing such challenges requires a sustained commitment to strengthening health systems, improving laboratory

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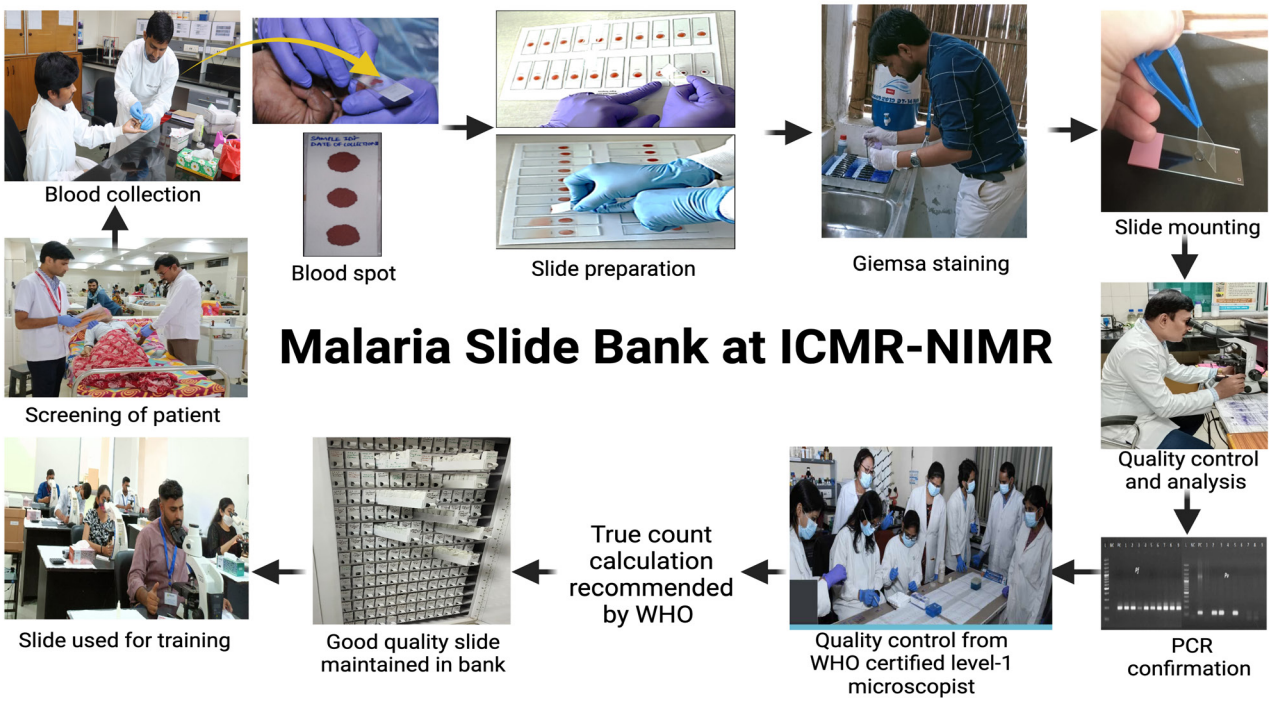

Figure 1. Stepwise representation of malaria slide bank in India. Abbreviation: WHO-World Health Organization; PCR-Polymerase Chain Reaction. All the images in the figure are subject to copyright owned by ICMR-NIMR.

infrastructure, and investing in training and capacity building for microscopists. The establishment of MSB holds immense value for national programs, as it offers QC slides encompassing a diverse range of parasitemia levels and various species, including mixed infections. During the process of sample collection for banking, there were notable challenges that emerged, particularly concerning the inadequate volume of blood obtained, particularly in children, and the delays encountered in transporting positive blood samples from the collection site to the slide preparation site. One of the notable limitations was the difficulty in obtaining rare species of malaria, such as *P. malariae* and *P. ovale*. These challenges posed significant hurdles to the establishment of MSB.

3. Malaria slide banks help training malaria microscopists

The MSB at ICMR-NIMR offers high-quality, well-prepared slides containing varying parasite counts to numerous health authorities, state governments, and regional health offices throughout India. The significant demand for these slides is primarily for microscopy training and regular assessment of microscopists, as recommended by state malaria programs. The availability of such slides is crucial for capacity building initiatives targeting malaria microscopists throughout the healthcare system. MSB's slides are utilized for the National Competency Assessment of Malaria Microscopists (NCAMM), to ensure that microscopists meet the required competency standards. Additionally, the slides are used for refresher training programs conducted in various states. The MSB also plays a vital role in assessing the competency of newly impaneled technicians to obtain certification from the WHO as L1/L2 technicians. By offering well-prepared slides of varying parasite counts, the MSB supports state malaria programs in their efforts to enhance the competency and proficiency of microscopists, ultimately contributing to improved malaria diagnosis and control outcomes in the country.

4. Malaria slide banks equipped with artificial intelligence and digital systems enhances malaria reporting

The integration and training of algorithmic systems in the artificial intelligence (AI)-based approach, facilitated by the MSB, can mitigate challenges and enhance the proficiency of laboratory technicians in malaria diagnosis using microscopy[8]. Digital scanning and archiving of stained malaria blood smears offer significant advantages. It enables easy access and retrieval of images for future reference and analysis. This digital approach eliminates the need for physical storage of slides, reduces the risk of slide damage or loss, and facilitates remote consultation and collaboration among experts. The availability of a comprehensive digital slide library also promotes research and data sharing, contributing to the advancement of malaria research[9]. Barcoding malaria slides can be another effective strategy to overcome challenges in malaria diagnosis training. By assigning unique identifiers to each slide, bias in slide selection can be minimized, ensuring a representative sample for analysis. Barcoding enhances traceability, making it easier to track and manage slides throughout the training process. It streamlines workflow by automating data entry and reduces the potential for errors or misinterpretation[4]. In summary, incorporating AI-based approaches can address various challenges by improving

the competency of laboratory technicians, enhance accessibility and data management, and contribute to the overall effectiveness of malaria diagnosis and control efforts.

5. Future directions: Expanding malaria slide banks and potential applications

The future of the MSB in India holds immense potential in advancing malaria diagnosis, research, and control efforts. As technology continues to evolve, the MSB can leverage digital advancements to enhance its functionality and impact by establishing partnerships with remote and underserved regions. This can support capacity building efforts, enable better surveillance and monitoring of malaria, and ultimately contribute to effective disease control and elimination. The future of the MSB in India, particularly post-malaria elimination, holds significant potential in several key areas. Firstly, the MSB can contribute to post-elimination surveillance and monitoring efforts. As cases of malaria decrease, it is challenging to maintain the necessary expertise and infrastructure for accurate diagnosis. MSB can support local health workers and laboratory technicians in maintaining their skills and expertise in malaria diagnosis and surveillance by providing a reliable source of well-preserved malaria slide. In a similar way, the MSB can be leveraged for training and capacity building in other areas of vector-borne diseases[10]. Many aspects of microscopy and slide preparation techniques used in malaria diagnosis can be applicable to other diseases, such as filariasis and Chagas disease[11]. However, it requires a significant investment in resources, infrastructure, and regulatory and policy support. This requires collaboration between local, national and international stakeholders, as well as a commitment to sustained funding and resources. In conclusion, the future of the MSB in India post-malaria elimination holds great promise. Its ongoing role in vital areas such as surveillance, training, capacity building, knowledge dissemination, and research initiatives will be pivotal in advancing public health and scientific understanding.

In conclusion, the MSB is an invaluable asset for a country like India, especially when malaria elimination program is on its way. The availability of MSB resources offers significant support to malaria control programs and microscopists in various capacities. An important aspect is the availability of microscopy QC slides with varying parasitemia levels. The QC slides serve as essential tools for training and proficiency assessment of malaria microscopists. The establishment of India's first MSB at ICMR-NIMR is a major milestone, ensuring the seamless implementation of state and national training programs. Moreover, the MSB's benefits extend beyond India, as it is also available to other countries in the Southeast Asian region. This cross-border accessibility further strengthens the collaborative efforts in malaria control and surveillance, fostering a collective approach in combating the disease. Currently, regional MSBs have been established in Africa and India, highlighting the progress made in these regions toward building comprehensive slide repositories for malaria research and training purposes.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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Authors' contributions

SN did the literature search and drafted the manuscript; NN, AA, and PKB gave intellectual comments, and reviewed the final version.

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