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RESEARCH ARTICLE

Achievements of the national malaria control and elimination program in the People's Republic of China: *the Atlas of Malaria Transmission in China*

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Abstract **In 2017, China achieved the target of zero indigenous malaria case for the first time, and has been certified as malaria free by World Health Organization in 2021. To further summarize the historical achievements and technical experiences of the elimination program, a project on the Roadmap Analysis and Verification for Malaria Elimination in China was carried out. Results of the project were compiled and published as *the Atlas of Malaria Transmission in China* (The Atlas). The Atlas using modern digital information technologies, has been supported by various data from 24 malaria endemic provinces of China since 1950, to assess the changes in malaria epidemic patterns from 1950 to 2019 at national and provincial levels. The Atlas is designed as two volumes, including a total of 1850 thematic maps and more than 130 charts, consisting of introductory maps, thematic maps of malaria epidemic and control at national and provincial levels. It objectively and directly shows the epidemic history, evolution process, and great achievements of the national malaria control and elimination program in China. The Atlas has important reference value for summing up historical experience in the national malaria elimination program of China, and malaria control and elimination in other endemic countries in the world.**

Keywords malaria; transmission; control; elimination; China; atlas

Introduction

Malaria has been prevalent in China for a long time in the history, and it was recorded as early as 3000 years ago [1]. Before 1949, malaria was widely distributed within the country with at least 30 million cases that occurred annually, with its mortality rate about 1% [2]. The national malaria control program in China can be primarily divided into five phases: (1) focal investigation and control phase (1949–1959); (2) severe epidemics control phase (1960–1979); (3) reducing incidence phase (1980–1999); (4) consolidation phase (2000–2009); and (5) elimination phase (since 2010) [3]. The epidemic has shrunken sharply after the implementation of an integrated strategy for malaria control for more than 7 decades [4,5]. Thus, in May 2010, the former Ministry of Health together with 12 other ministries issued the National Malaria Elimination Action Plan (2010–2020) (NMEAP) [6], aiming to eliminating malaria nationwide by the end of 2020.

It is noted that malaria elimination in China is a country-owned and country-led endeavor [3]. In 2017, China achieved the target of zero indigenous malaria case for the first time, and has continued to maintain no indigenous case up to now, which has met the requirement of World Health Organization (WHO) guideline for malaria elimination certification [7]. However, as international exchanges become more frequent, there are still nearly 3000 imported malaria cases reported every year in the country, and distributed in every province of the country [8–11]. In addition, a large number of imported malaria cases introduced great challenges to the preventing re-establishment of malaria transmission due to the insignificant change of the malaria vector breeding conditions in the country [12].

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Therefore, it is still necessary to maintain sufficient and long-term surveillance and response capacity to consolidate the achievements of malaria elimination.

China has accumulated a wealth of valuable information and experience in the process from malaria control to elimination, especially in the context of building a community with a shared future for humanity and the "Belt and Road" initiative [13]. These data and experience are the resources for the historical treasure-trove, which not only contribute to the global program in fighting against malaria, but also transfer Chinese wisdom to the world. Therefore, these historical materials urgently need to be reorganized, distilled, preserved, and utilized through digital forms. To further summarize the historical achievements and technical experiences from the national malaria control program in China, in this study, we summarized the achievements from malaria control and elimination program supported by the data and maps in *the Atlas of Malaria Transmission in China* (The Atlas), based on the analysis of malaria incidence patterns since 1950 and changes of the case-based malaria reporting data since 2010. The Atlas could provide a good model on how to distil a country's historical experience in disease control program, and how to plan a country's malaria elimination program in other endemic countries of the world.

Methods

Atlas design

Since 2012, the National Institute of Parasitic Diseases (NIPD) at Chinese Center for Disease Control and Prevention has organized a project on the Roadmap Analysis and Verification for Malaria Elimination in China which was implemented in 24 malaria endemic provinces across the country, by collecting data from the national malaria control program, analyzing the changing patterns of malaria incidence in China in the form of numerous thematic maps and data charts, so that all of the results on the effectiveness and evolutional features of the national malaria control and elimination program, with an assistance of geographic information systems and spatiotemporal analysis technology, were compiled and published as The Atlas [14].

Data collection

The data used in The Atlas was obtained from thematic surveys from 1950 to 2010 in 24 malaria endemic provinces across the country. The epidemic data since 2010 when the NMEAP was launched covered all 31 provinces/municipalities/autonomous regions in China. The data on malaria transmission after 2004 was extracted from the National Notifiable Disease Reporting System (NNDRS), which was set up in 2004 after the severe acute respiratory syndrome outbreak and is a standardized platform that provides healthcare systems nationwide with the ability to detect, analyze, prevent, and respond to the notifiable communicable diseases in the country. For the malaria data after 2012, it was derived from The Parasitic Diseases Information Reporting Management System (PDIRMS) to observe and document cases within the time frame indicators utilizing the "1-3-7" approach. Since 2017, the endemic provinces were classified into 4 regions, including southeast (Zhejiang, Shanghai, Jiangxi, Hunan, Fujian), southern (Chongqing, Yunnan, Guizhou, Guangdong, Guangxi, Hainan, Tibet), central (Jiangsu, Shandong, Hubei, Henan, Anhui) and northern (Xinjiang, Shannxi, Shanxi, Hebei, Liaoning, Gansu), the total number of malaria cases and the average annual incidence for each region in the different phases were collected and analyzed. The administrative boundary maps of the country and provinces/municipalities/autonomous regions were adopted with digital maps of 2018.

Data analysis

The data were chosen by utilizing the variables including reviewing data and reporting area, but the data from Hong Kong, Macao, and Taiwan were not included in these statistics. The variables including number of cases, *Plasmodium* species, geographical location, gender, and age of the cases were extracted from the NNDRS database. The variables, such as vector distribution and control, case classification (indigenous, imported, induced, or introduced), case management including case report, diagnosis, treatment, and investigation, were retrieved from the PDIRMS database. For the incidence in 4 joint control and prevention regions, it was created by GraphPrism (Version 9.0.0, San Diego, CA, USA).

Results

Outlines of The Atlas

The Atlas has been published by the Sinomap Press in 2021 [14], which is designed in octavo format, as two volumes, including a total of 1850 thematic maps and more than 130 charts. The Atlas consists of introductory maps, thematic maps of malaria epidemic and control in China, and thematic maps of malaria epidemic and control at a provincial level (Fig. 1). The introductory maps include: countries of the world, administrative divisions of China, population density of China, topography of China, climate of China, land cover of China, China GDP per capita, and the global malaria

Fig. 1 Schematic framework of *the Atlas of Malaria Transmission in China*.

status. The status of malaria epidemic and control in China includes: malaria transmission stratification of China, the number of malaria cases in China, malaria incidence and *Plasmodium* species in China, malaria case classification in China, distribution of malaria vectors in China, malaria case management in China, malaria vector control in China, national sentinel sites for malaria surveillance, and risk map for malaria transmission in China, etc. Malaria epidemic situation and control at a provincial level of each province/municipality/autonomous region includes: administrative divisions of provinces, and the number of malaria cases as well as the incidence for each year.

Malaria incidence in China

In 1950–2010, a total of 225 million malaria cases were reported in China, with 35 959 reported deaths. Prior to 1949, there was approximately 30 million malaria cases yearly nationwide. The malaria incidence has been steeply reduced, the total number of cases and average annual incidence were listed for each decade from 1950 to 2009 (Table 1). Specifically, there were 10 236 754 cases with 1553.85/100 000 reported in 1960, 24 115 018 cases with 2961.1/100 000 in 1970, 3 300 349 cases with 337.83/100 000 in 1980, 117 359 cases with 10.56/100 000 in 1990, 24 088 cases with 1.88/100 000 in 2000, 7851 cases with 0.6/100 000 in 2010, respectively. From 2011 to 2019, a total of 29 192 malaria cases and 159 deaths were reported. The malaria cases reported were 2674 in 2019, declined by 39.9% comparing with that in 2011 (n = 4450).

Distribution of *Plasmodium* species

The distribution of *Plasmodium* species was presented each year in The Atlas. In the period of 1950−1960, the blood examination showed that *P. vivax* infections accounted for 52.1%, *P. falciparum* infections accounted for 36.9%, *P. malariae* and *P. ovale* infections were sporadically found (more than 7.5%). In 1960–1979, *P. vivax* predominated and took up 92.0% of all 45 552 malaria cases nationwide in 1979. From 1980 to 1994, *P. vivax* infections still predominated in the malaria cases reported each year, the proportion ranged from 86.2% to 97.7%. In 1995–2010, among all the reported confirmed

Table 1 Malaria cases and incidence in different phases of the national malaria control and elimination program in China

Phase	Year	Number of cases	Average incidence (1/100 000)
Key-point investigation and control	1949−1959	31 782 036	555.85
Control of severe epidemics	1960−1969	68 842 698	977.86
	1970−1979	114 010 009	1323.68
Reducing incidence rate	1980−1989	12 092 153	120.62
	1990−1999	595 460	5.12
Consolidating the control achievements	2000−2009	352 229	2.87
Elimination phase	2010−2019	37 043	–[a]

[a]Since imported cases were predominant during elimination phase, so herein we cannot calculate the real incidence.

cases, 479 269 (82.2%) were *P. vivax* cases, 48 414 (10.1%) *P. falciparum* cases, and 36 810 (7.7%) were other *Plasmodium* specie cases. The *Plasmodium* species have changed due to the increased proportion of the imported *P. falciparum* cases from Africa and significantly reduced proportion of the indigenous malaria cases since 2008. From 2011 to 2019, a total of five *Plasmodium* species were identified among all confirmed cases, including *P. falciparum* (n = 17 350 (59.4%)), *P. vivax* (n = 7584 (26.0%)), *P. ovale* (n = 2053 (7.0%)), *P. malariae* (n = 535 (1.8%)), and *P. knowlesi* (n = 2), as well as mixed infections (n = 359 (1.2%)). The proportion of *P. falciparum* in confirmed cases rose from 40.1% in 2011 to 73.1% in 2019, and the proportion of *P. vivax* decreased from 55.7% in 2011 to 10.8% in 2019.

Classification of malaria cases between indigenous and imported ones

From 1950 to 2010, the occurrence of indigenous malaria has been steeply reduced. In 2010, there were only 4262 indigenous cases reported, after substantial efforts invested in the national malaria elimination program, only 1 indigenous case was reported in 2016, reduced by 99.9% compared to 2010 (Fig. 2). In 2017, for the first time, no indigenous case was reported. In 2017–2019, no indigenous cases had been reported for 3 consecutive years. However, the proportion of imported cases increased from 54.7% in 2011 to 99.9% in 2019. The total imported cases from 2011 to 2019 were 27 088, with a predominant species of *P. falciparum* presented (n = 17 192 (63.5%)).

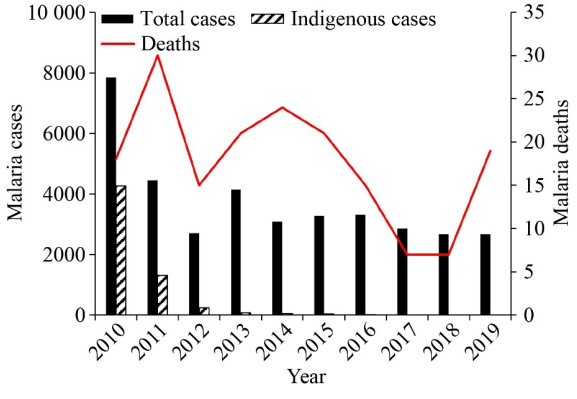

Fig. 2 Total malaria cases, indigenous cases, and deaths in China, 2010−2019.

Malaria case management

Case management, including case detection, diagnosis, reporting, investigation, and treatment, was of crucial for malaria control and elimination program. China has carried out blood examination activities for the whole malaria control phases during 1980−1989, it has the highest number of blood examinations with 116 076 087 (Fig. 3A). The active case detection (ACD) was also conducted and 1970−1979 period harboured the highest number of ACD cases with 16 788 838 (Fig. 3A). The highest number of case treatment, patients with radical treatment, and patients with prophylaxis were observed in the period of 1970−1979 with 80 209 230, 218 941 009, and 611 234 977, respectively (Fig. 3A). The national drug policy of China was updated in 2006, and the first-line drugs used to treat uncomplicated *P. falciparum* have been artemisinin-based combination therapies (ACTs), including dihydroartemisinin-piperaquine (DHA-PPQ), artesunate-amodiaquine (AS-AQ), artimisinin-naphthoquine phosphate (ART-NQ), and artemisinin-piperaquine (ART-PPQ). As for *P. vivax* and *P. ovale*, chloroquine plus primaquine was the recommended antimalarial administered as 8-day regimen. Also primaquine was applied as radical cure of *P. vivax* and *P. ovale* infection with 8-day regimen before next transmission season. So far, the artemisinin-resistance *P. falciparum* and chloroquine-resistance *P. vivax* strains have not been seen in the country.

Vector control interventions

Insecticide-treated bed nets (ITNs) have been used as one of the main strategies for vector control in China, particularly pyrethroid insecticides such as deltamethrin.

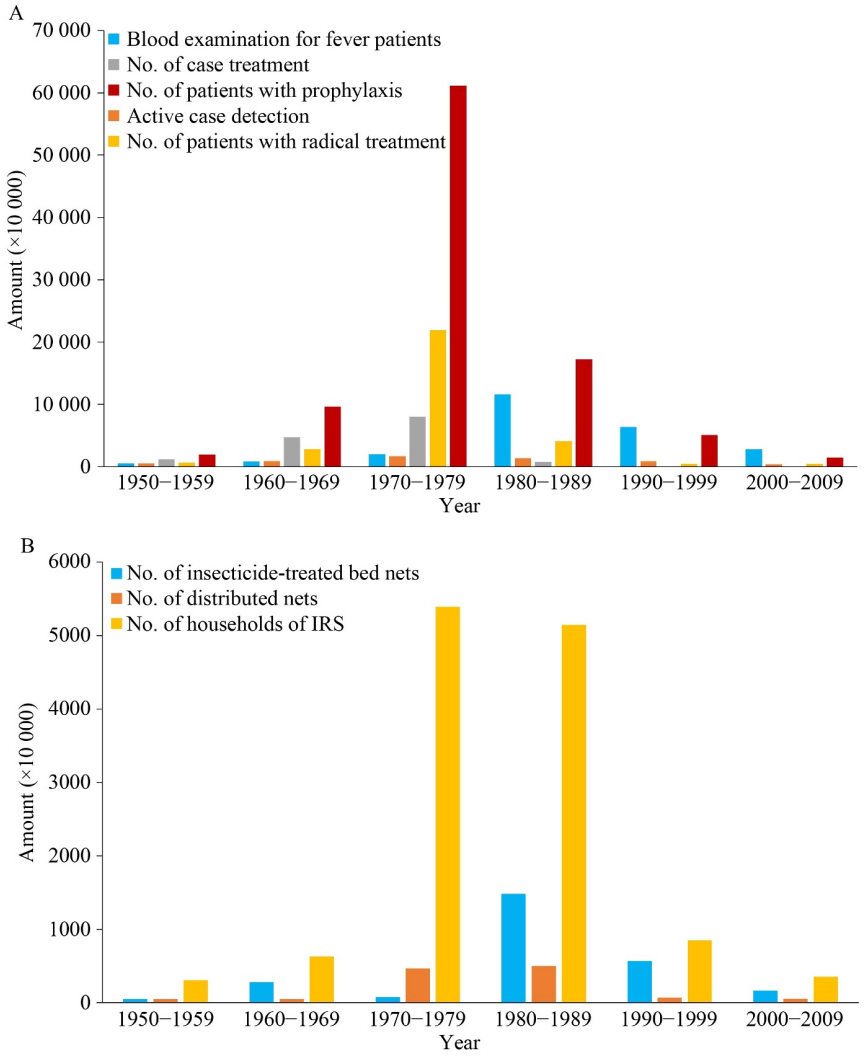

Fig. 3 Malaria case management (A) and vector control interventions (B) in different phases of the national malaria control and elimination program in China.

In 1950−2009, a total of 26 191 800 bed nets were treated with insecticides and the period of 1980−1989 has the highest number with 1 428 963 (Fig. 3B). The total of distributed nets treated with insecticide were 11 919 520 and mainly distributed in 1970−1979 (n = 4 648 814, 39.0%) and 1980−1989 (n = 5 009 434, 42.0%). Indoor residual spraying (IRS) with insecticides such as pyrethroids was at active foci to reduce *Anopheles* spp. density and interrupt possible transmission. The number of households by IRS were mainly observed in 1970−1979 and 1980−1989 with 53 898 711 and 51 431 545 households, respectively (Fig. 3B).

Malaria cases and incidence in four joint control regions

We have analyzed the average annual incidence for four joint control regions in different phases. During 1950−1959, the southeast, southern and central regions had accounted for 14.6%, 35.7% and 48.5% of all cases. The cases of 1960−1969 (88.6%), 1970−1979 (87.7%), and 1980−1989 (70.6%) were all clustered in the central region. After 1990, southern region has increasingly taken up the high proportion of all malaria cases since 52.8% and 63.4% of all cases were reported in this region in 1990−1999 and 2000−2009, respectively. For malaria incidence, it was observed the highest in central region in 1970−1979 with 3779.3 per 100 000 (Fig. 4). After 1990, the disease burden was mainly in southern region with 161.1 per 100 000 and 42.4 per 100 000 observed in 1990−1999 and 2000−2009, respectively (Fig. 4).

Discussion

To achieve malaria elimination in China is not only a great work contributing to contemporary times and

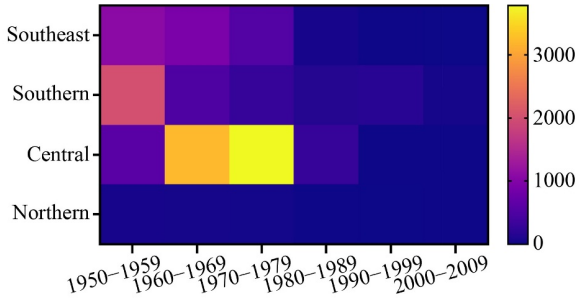

Fig. 4 The malaria incidence in different regions in different phases of the national malaria control and elimination program in China.

bringing benefits for future centuries, but also the inevitable requirements and important contents in succeeding target of the Healthy China 2030, promoting the health poverty alleviation program in China. Therefore, the function of The Atlas presented has reflected in following three aspects. First, it has clearly displayed the detail trend of disease burden in the different control phases by year from 1950 to 2010 via thematic maps, including number of cases, incidence, *Plasmodium* species, this exhibited the evolution of China's malaria control program and its effectiveness by the changes of the spatiotemporal distribution patterns of malaria in China, which could fill the data gap across whole period of the national malaria control and elimination program in China. Secondly, the malaria transmission stratification described in The Atlas was classified by year and by county in national level and in provincial level including all 24 endemic provinces, which could be used as evidence-based proof for the next adjustment of strategies and interventions, especially for preventing of re-establishment of malaria transmission during post-elimination stage with tailored activities in different regions [15]. For example, in the China–Myanmar border, though no indigenous case occurred since 2017, active case detection is needed to maintain malaria free status besides the improvements to "1-3-7" approach due to the frequently cross-border mobile population [16,17]. Proactive mapping of disease transmission hot spots and the genetic diversity and population dynamics are effective means of facilitating early detection, allowing prompt treatment using efficacious drugs [18]. For other provinces where *P. falciparum* was distributed such as southern and central regions of China, the prioritizing of surveillance and response activities make every imported case obtain timely diagnosis and promptly treatment [19]. Thirdly, achieving universal health coverage (UHC) is one of the targets that the world set when adopting the UN Sustainable Development Goals in 2015 [20]. Countries that progress toward UHC will make progress toward the other health-related targets, such as end of malaria epidemic by sustained surveillance and prompt response for each malaria foci. The Atlas has set forth the country's historical experience in China and could be used by other countries which are on the same path. Currently, China has initiatives in cooperation with countries in Africa and Southeast Asia under the framework of such as the Silk Road Economic Belt and the 21st Century Maritime Silk Road [13]. Therefore, the Chinese experience on malaria control and elimination will implement and promote malaria control and elimination in the other endemic countries and regions through collaboration projects such as the UK−China−Tanzania Pilot Cooperation on Malaria Control Project, and Bill & Melinda Gates Foundation (BMGF)−China−Tanzania Cooperation Project on Malaria Control [21,22].

Based on the fact that China has made great strides in managing malaria over the last seven decades, zero indigenous case was reported for 4 consecutive years since 2017. In November 2020, China has formally applied to WHO for national malaria elimination certification, as well as the announcement that China was certified malaria-free by the WHO [23], which indicated that China has entered a new era to intensively sustain zero local transmission of malaria [24]. After malaria elimination, to prevent malaria re-establishment requires the country still adhere to government leadership, departmental cooperation, and participation of the whole society, further improve the joint mechanism covering inter-departmental, regional, military and local areas, and strengthen information exchange by improving the information sharing mechanism [25]. Besides, there are still several challenges in the post-elimination process in China. First, the country should maintain the non-transmission status nationwide [26]. This is of crucial because once the sustained importance on elimination interventions has waned, malaria could be re-introduced in areas where it has been previously eliminated. This could also be learnt from the case reports of Liaoning, Hainan and Hunan provinces [27–29]. Secondly, the country should overcome the difficulties in border areas, particularly on the China–Myanmar border. In border area, both investigation and foci disposal for the "1-3-7" approach and the "3+1 line of defense" have been developed and implemented [30–32].

Conclusions

The Atlas is the first time to display the history of malaria control and elimination in China by the means of temporospatial distribution. It systematically provides a large number of valuable historical data on malaria in different phases in China, and objectively and vividly shows the epidemic history, evolution process and great achievements of the national malaria control and elimination program in China in the form of thematic

maps combined with data charts. The Atlas has important reference value for summing up the malaria control experience and planning China's malaria elimination program, as well as malaria control in other endemic countries in the world [33]. It will help the further understanding of the transition of China's comprehensive control strategy that focused on controlling the source of infection in the control phase to the strategy of blocking transmission for each focus during the elimination phase, and can also be used as supporting evidence for malaria elimination certification in the country [34].

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Compliance with ethics guidelines

Jun Feng, Li Zhang, Zhigui Xia, Shuisen Zhou, Ning Xiao, and Xiao-Nong Zhou declare that they have no competing interests. The data in the study were obtained from paper-source and web-source, therefore the ethics and participatory consent was not needed, and this study was approved by the National Institute of Parasitic Diseases, Chinese Center for Diseases Control and Prevention.

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