



OPEN Development of human resources in malaria microscopy during and after the malaria elimination phase in China

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Under the context of sustained low malaria incidence in China, maintaining an adequate number of qualified microscopists remains a critical component to ensure and sustain the success of malaria elimination. Therefore, this paper presents the efforts made, achievements attained, and future prospects regarding the development of human resources in malaria microscopy during and after the malaria elimination phase in China. To confirm the competence of malaria microscopists at the national level, six rounds of the External Competence Assessment of Malaria Microscopists (ECAMM) courses, developed and administered by the World Health Organization (WHO), were conducted in China from 2017 to 2024. The number and frequency of certified microscopists participating in the WHO-ECAMM courses were retrospectively reviewed. To support the establishment of core groups at sub-national levels, a model course for the National Competency Assessment of Malaria Microscopists (NCAMM) was revised in accordance with WHO guidelines and implemented from 2019 to 2024. The course schedule and scoring system were detailed, including improvements in evaluation metrics. Participants' competency levels (A, B, C, and D) were determined based on standardized criteria. The relationship between participants' competency levels and their age or years of experience in malaria microscopy, as well as variations in their scores, was analyzed. To guide the future qualification of microscopists in peripheral areas, a proposed framework for human resource development of malaria microscopists was presented, based on the current malaria situation in China. A total of 64 microscopists participated in the six WHO-ECAMM courses. The average age of these participants in 2024 is 41.0 years. Among them, 29 individuals certified at Level 1 and 17 individuals at Level 2 covered National Institute of Parasitic Diseases (NIPD) as well as 29 out of 31 provinces. In addition, among the 72 participants who attended the six NCAMM courses, 10 were certified at Level A (the highest level), and 33 at Level B. Factors such as age, place of employment, educational background, and gender did not show a significant impact on participants' competence in malaria microscopy ($n=72$; $p=0.2$, $P>0.05$). However, the number of years of experience in malaria microscopy demonstrated a moderate positive correlation with competence levels ($n=72$; $p=0.4$, $P<0.01$). Notably, scores for species identification (SI) improved significantly ($Z=-7.3$, $P<0.01$). The proposed structure for human

resource development of malaria microscopists includes three core groups operating at the national, sub-national (provincial), and sub-provincial levels. This structure recommends the application of four models for assessing microscopists' competence. Based on six WHO-ECAMM courses, the national core group of malaria microscopists was re-affirmed. The NCAMM courses conducted in China have demonstrated effectiveness as both an evaluation system and a refresher training model. They are expected to be widely implemented at both national and subnational levels to support the development of human resources in malaria microscopy. The predefined structure for human resource development of malaria microscopists provides a systematic framework for assessing and defining the competencies of microscopists in peripheral areas.

Keywords National competency assessment of malaria microscopists (NCAMM), Smear preparation (SP), Parasite detection (PD), Parasite species identification (SI), Parasite counting (PC)

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By 2025, twenty countries that were malaria endemic in 2000, including China, have been officially certified as malaria-free by the World Health Organization (WHO)¹. Although global malaria elimination programs have made significant progress in recent years, malaria remains a substantial public health challenge worldwide. In 2024, approximately 282 million individuals were infected with malaria, resulting in an estimated 610,000 deaths¹. China maintains regular communication with other countries and regions. According to official statistics, China processed approximately 610 million entries and exits of individuals in 2024, of which 291 million involved mainland residents traveling in and out of the country². On average, around 3,000 malaria cases were reported annually across 31 provinces in China since 2011, corresponding to an incidence rate of approximately 2.1 cases per million population (3,000/1.4 billion). Despite this relatively low incidence, the disease resulted in a significant number of severe cases and a case fatality rate of 4.8 per thousand ($n = 8$, $\pm 1.8\%$, 95% CI: 3.3–6.3%). Furthermore, imported *Plasmodium vivax* cases and its primary vector, *Anopheles sinensis*, are widely present in previous malaria-endemic provinces of China^{3–8}. Therefore, China continues to face a risk of malaria resurgence.

To prevent severe malaria, malaria-related fatalities, and the re-transmission of malaria in malaria-free regions, the principles of early detection, early diagnosis, and early treatment—collectively referred to as the “Three Early” strategy—are widely recognized as essential global practices. However, given the persistently low incidence of malaria during and after its elimination in China, large-scale, comprehensive resource allocation—including specialized testing reagents, materials, and human resources—is clearly impractical. Nevertheless, shortages in these areas have led to misdiagnoses and delayed diagnoses, serving as notable warnings⁹. Among the available diagnostic methods for malaria—Rapid Diagnostic Tests (RDT), Nucleic Acid Testing (NAT), and microscopy—microscopy remains the gold standard and is considered the most feasible option for surveilling malaria cases at health institutions at various levels including county and even some townships under the current epidemiological context in China. This principle is reflected in the National Surveillance Program during the Post-Malaria Elimination Period (2025 Edition) (NSP-2025). Therefore, to ensure the effective implementation of the “Three Early” strategy and to uphold the high-quality execution of the NSP-2025, it is essential to maintain a sufficient number of qualified microscopists across the country. Simultaneously, establishing effective mechanisms to sustain their diagnostic competence is equally critical.

The External Competence Assessment of Malaria Microscopists (ECAMM), developed and implemented by WHO, serves as a well-established model for evaluating the competence of malaria microscopists and has been widely adopted by malaria-endemic countries globally^{10,11}. Microscopists qualified in WHO-ECAMM courses are the best proof of a strong surveillance system required to certify and sustain malaria elimination¹². The National Institute of Parasitic Diseases (NIPD) under the China Center for Disease Control and Prevention (CDC), which oversees the national malaria control program, has organized ten WHO-ECAMM courses between 2009 and 2024. However, due to the limitation that no more than one microscopist per province could participate every three years, the demand for certified malaria microscopists remains largely unfulfilled in China, particularly at the subnational level^{13,14}.

The National Competency Assessment of Malaria Microscopists (NCAMM) is another model proposed by WHO, specifically designed to support domestic external competence assessments in malaria microscopy. To date, however, no NCAMM implementation has been reported globally. In 2018, three Chinese facilitators were jointly trained and certified by the WHO Western Pacific Region Office, the Asian Collaborative Training

Network for Malaria, and NIPD. Based on WHO guidelines, these facilitators successfully conducted six updated NCAMM courses between 2019 and 2024.

This document presents the efforts and achievements in human resource development for malaria microscopists in China, along with future prospects. First, it summarizes the certified malaria microscopists assessed through WHO-ECAMM courses in China. Next, it introduces the updated NCAMM courses, supported by an analysis of assessment data. Finally, it proposes a conceptual framework for the future development of human resources for malaria microscopists in China.

Methods

Certified malaria microscopists in WHO-ECAMM courses between 2017 and 2024 in China

Data on participants who attended the WHO-ECAMM courses between 2017 and 2024 in China were collected. The number and distribution of certified microscopists across different levels were calculated at the provincial level.

NCAMM courses implemented between 2019 and 2024

Organization of six NCAMM courses and collection of participants’ information

NIPD, either independently or in collaboration with provincial CDCs, organized six NCAMM courses. Each course was conducted with the support of one to three certified facilitators. Comprehensive data were systematically collected regarding participants’ affiliated institutions, gender, educational background, age, and years of experience in malaria microscopy.

NCAMM course schedule and scoring system

The NCAMM course was a structured five-day program that includes a theoretical examination, pre-assessment, and final evaluation (as detailed in Table 1), all of which align with WHO’s guidelines^{10,11}. The key distinction of the schedule conducted in China was that the theoretical and skill-based presentations were scheduled toward the end of the program in the earlier versions.

For the Smear Preparation (SP) grading, a total of 13 quality criteria were evaluated (as detailed in Table 2). These criteria had been updated since their initial establishment in 2019¹⁵. Each criterion was scored as either “Yes” (1 point) or “No” (0 points), with one point allocated per criterion. The total score for each prepared slide was calculated, and slides achieving 12 or more points out of 13 are considered qualified. The percentage of qualified slides prepared by each participant during the final assessment period (Days 2–4) served as one of the key indicators for determining participants’ competence levels. From Days 1 to 3, participants were provided with seven blank slides daily for blood film preparation. Each day, the five best-prepared slides from each participant were evaluated according to the established quality criteria. On Day 4, participants were given five blank slides, and three thick and thin smears prepared from freshly collected finger-prick blood samples were assessed using the same evaluation criteria.

The composition of the NCAMM slide panels was largely consistent with the methodology employed by the WHO-ECAMM^{10,11}, with the exception of slides including two species (two slides in total in the final test)

0800–0915	0915–0945	0945–1215	1215–1300	1300–1330	1330–1545	1545–1700 (Presentation)
D1						
Registration Introduction of NCAMM, Theory Test & Feedback	Pretest: Slide making (5/7 Slides)	Pretest: Slide Examination (9 slides)	Lunch	Pretest: Slides Staining	Pretest: Slide Examination (9 slides)	1.Slides preparation and assessment criteria 2. Blood elements & artefacts and skills of malaria microscopy (simple version)
D2						
Answer feedback and slides Review	Final test: Slide making (5/7 Slides)	Final test: Slide Examination (10 slides)	Lunch	Final test: Slides Staining	Final test: Slide Examination (9 slides)	1.Blood elements & artefacts and skills of malaria microscopy (detailed version) 2.Skills of parasite counting
D3						
Answer feedback and slides Review	Final test: Slide making (5/7 Slides)	Final test: Slide Examination (10 slides)	Lunch	Final test: Slides Staining	Final test: Slide Examination (9 slides)	1.Skills of collecting blood from finger and making slides 2.Establishment of malaria slide Bank(changeable)
D4						
Answer feedback and slides Review	Final test: Slide making using Finger blood (3/5 Slides)	Final test: Slide Examination (10 slides)	Lunch	Final test: Slide Staining	Final test: Slide Examination (8 slides)	QA in Malaria Laboratory Diagnosis (changeable)
0800–0915	0915–1045		1100–1200	1200–1300	1300–1600	
D5						
Announcement of results and slides review	Clinical diagnosis, treatment and case sharing (changeable)		Course conclusion and award ceremony	Lunch	Departure	

Table 1. Agenda of NCAMM course.

Criteria Items for SP		Yes/No
1	The blood smear is unique labeled and the label is located at the end near the thick film	
2	Diameter of thick film is 10 ~ 12 mm, even and more than 90% is intact	
3	The thick film is adequate thickness. Averagely 10 ~ 20 white blood cells per field	
4	The position of thick film is right (Distance from center of thick film to the nearest short edge ≥ 30 mm)	
5	There are three parts of thin films, head, body and tail with no waves	
6	There are adequate space between thick and thin films (≥ 5 mm)	
7	There are adequate space between thin film and edges of slide (≥ 5 mm short edge, ≥ 1 mm long edge)	
8	The thin film is adequate size (length and width are both ≥ 20 mm)	
9	The white blood cells are properly stained (nucleus is purple to black)	
10	The red cells are completely lysed in thick films (Diameter of lysed area is more than 8 mm)	
11	Red cells show single layer towards the feathered edge	
12	The red blood cells are properly stained (grey to pink)	
13	The films are clearly and no debris. The background is transparent	

Table 2. Criteria items for slides preparation. Yes for 1 point, No for 0 point; Slides with ≥ 12 points is qualified.

Levels	PD (%)	SI (%)	PC(%)	SP*(%)
A	90–100	90–100	50–100	90–100
B	80–89	80–89	40–49	80–89
C	70–79	70–79	30–39	70–79
D	0–69	0–69	0–29	0–69

Table 3. Standards to certifying participants’ different competence of malaria microscopy¹¹. Notes: * Smear Preparation.

and non-falciparum species (eight slides in the final test). These components could be tailored according to the local malaria epidemiological profile. For the parasite counting test, which comprises 14 slides in the final assessment, six slides with parasite densities ranging from 800 to 6,000 parasites/μL were included. The highest parasite density category, represented by two slides, was defined as 12,000–20,000 parasites/μL rather than 40,000–100,000 parasites/μL due to limitations in slide availability. At least 16 *P. falciparum* slides with low parasite density (200–700 parasites/μL) were selected for species identification ($n = 10$) and counting ($n = 6$). The slide panels used in the pre-test were identical to those used in the WHO-ECAMM^{10,11}. Two to three slides might be repeated between the pre-test and the final test. Participants were evaluated based on their accuracy in malaria parasite detection (PD), species identification (SI), and parasite counting (PC). Scoring is calculated using the following equations:

$$\begin{aligned} \text{PD (\%)} &= \frac{\text{The number of positives noted by the participants}}{\text{The number of all true positives}} \times 100\% \\ \text{SI (\%)} &= \frac{\text{The total points obtained by the participant}}{2 \times \text{The total number of slides for species identified}} \times 100\% \\ \text{PC (\%)} &= \frac{\text{The total points obtained by the participant}}{3 \times \text{The total number of slides for parasite counting}} \times 100\% \end{aligned}$$

For the SI component, the final test consists of a total of 22 positive slides. Two points were awarded for accurate identification. If only one species was identified in a mixed infection scenario, one point was given, whereas zero points were assigned if two species are reported when only one is present. Furthermore, three points were awarded if the participant’s count is within 25% of the actual count, one point if the count falls within 50% but not within 25%, and zero points if the count is less than 50% of the true value.

Assessment of competence level in malaria microscopy
Participants are classified into competence levels A, B, C, or D based on the scoring criteria for PD, SI, PC and SP, as outlined in WHO’s documentation (Table 3)¹¹.

Anonymous satisfaction surveys
After each NCAMM course, anonymous satisfaction survey was conducted, which included ten questions regarding course content and delivery. However, the results of the surveys were not included in this manuscript, as all participants provided high evaluation scores.

	Chances				Competence levels		
	Once	Twice	Tree times	Four times	1	2	Others
No. of microscopists	57	6	1	None	29	17	18
No. of Provinces	3	21	6	1	22	14	11

Table 4. Microscopists certified in different provinces between 2017 and 2024.

Order	Time	Organizers	Participants' units		Sex		Education degree	
			Provincial Units	Sub-provincial Units	Female	Male	Master	Bachelor
1st	2019	NIPD	9	3	8	4	8	4
2nd	2021	Province 1	2	10	11	1	4	8
3rd	2023	Province 1	4	8	7	5	8	3
4th	2023	Province 2	3	9	8	4	3	9
5th	2024	Province 3	6	6	5	7	2	10
6th	2024	NIPD	12	0	9	3	6	6
Total			36	36	48	24	32	40

Table 5. Six NCAMM courses in China and participants' basic information.

Data analysis

Data were analyzed using SPSS Statistics 23. Initial normality tests were conducted to assess the distribution of the data. Results were presented as means with standard deviation or medians with interquartile ranges (25th and 75th percentiles). For data that were not normally distributed, the Wilcoxon test and Fisher's exact test ($\alpha=0.05$) were used. An ordinal regression analysis was conducted, incorporating Spearman's correlation coefficient, to examine the relationship between participants' competence levels in malaria microscopy and their age (when they attended the NCAMM course) or years of experience in malaria microscopy.

Pre-assumed structure of human resource development for malaria microscopists in China

Based on the spatial distribution of malaria cases at provincial, sub-provincial, and county levels in 2023 and 2024, as well as the requirements outlined in the NSP-2025, a pre-assumed structure for the development of human resources for malaria microscopists at different administrative levels in China was proposed.

Results

Malaria microscopists certified in WHO-ECAMM courses between 2017 and 2024

In total, 64 microscopists participated in the six WHO-ECAMM courses conducted in China between 2017 and 2024. Prior to China being certified as malaria-free in 2021, four of these courses were held between 2017 and 2019. Participants in these courses were selected from NIPD and 31 provinces across the country. In 2024, two additional courses were conducted to reassess the participants and evaluate newly nominated microscopists, particularly those from provinces with relatively low malaria incidence between 2019 and 2023.

Among the 31 provinces, 21 were granted two opportunities to nominate microscopists for participation in the WHO-ECAMM courses, three provinces were given one opportunity, six provinces were provided three opportunities, and one province was given four opportunities (see Table 4).

Among the 64 microscopists, 57 participated once, six participated twice, and one participated three times. Of these individuals, 29 were certified at level 1, 17 at level 2, and 18 at level 3 or 4. Microscopists certified at level 1 or 2 represented the NIPD and 29 provinces (see Table 4). Among them, 15 were male and 31 were female. The median age (in 2024) of these microscopists is 41.0 [36.0–46.0] years ($n=46$). If we consider participation starting from 2012, seven participants attended the courses twice and seven attended three times. All of them have been engaged in malaria microscopy over the past decade. Most of them (13 out of 14) demonstrated improvement in their competence or maintained a high level of proficiency. The detailed outcomes are as follows: four were certified at level 1 three times, one was certified at level 1 twice, one was certified at level 2 twice, one improved from level 2 to level 1, four improved from level 3 or 4 to level 2 or 1 either directly or stepwise, one decreased from level 1 to level 2, and one decrease from level 1 to level 3.

Findings of NCAMM courses in China

Among the 72 participants in six NCAMM courses, 48 were female and 24 were male; 36 were from provincial-level units and 36 from sub-provincial-level units. With regard to educational background, 32 participants held master's degrees and 40 held bachelor's degrees (see Table 5). The majority of participants were aged between 32.0 and 40.0 years ($n=72$; median = 35.0). Additionally, all participants had more than 6 years of experience in malaria microscopy ($n=72$; 6.5 years (Q1–Q3:2.0–10.0)).

In total, 10 out of 72 participants were certified at Level A, 33 at Level B, and 28 at Level C or D. In the second and fourth courses, a higher proportion of participants achieved Level A and B certifications compared to those

Courses	Organizers	No. of participants				Fisher's Exact Test between different courses				
		A	B	C	D	2nd	3rd	4th	5th	6th
1st	NIPD	0	6	3	3	$\chi^2=7.8$ $P<0.01$	$\chi^2=2.5$ $P>0.05$	$\chi^2=8.4$ $P<0.05$	$\chi^2=1.6$ $P>0.05$	$\chi^2=3.1$ $P>0.05$
2nd	Province 1	2	10	0	0	/	$\chi^2=7.9$ $P<0.05$	$\chi^2=3.1$ $P>0.05$	$\chi^2=11.8$ $P<0.01$	$\chi^2=11.8$ $P<0.01$
3rd	Province 1	2	4	2	4	/	/	$\chi^2=5.7$ $P>0.05$	$\chi^2=4.2$ $P>0.05$	$\chi^2=3.1$ $P>0.05$
4th	Province 2	5	6	1	0	/	/	/	$\chi^2=10.3$ $P=0.01$	$\chi^2=8.5$ $P<0.05$
5th	Province 3	0	4	6	2	/	/	/	/	$\chi^2=1.3$ $P>0.05$
6th	NIPD	1	3	6	2	/	/	/	/	/
Total		10	33	18	11	/				

Table 6. Results and comparison of 6 NCAMM courses.

Factors		No. of Participants with different competence of malaria microscopy				Total	Fisher's exact test
		A(n=10)	B(n=33)	C(n=18)	D(n=11)		
Units	Provincial level	5	13	13	5	36	$\chi^2=5.1$ $P>0.05$
	Sub-provincial level	5	20	5	6	36	
Education Degree	Master	4	13	9	6	32	$\chi^2=1.2$ $P>0.05$
	Bachelor	6	20	9	5	40	
Sex	Female	7	24	10	7	48	$\chi^2=1.7$ $P>0.05$
	Male	3	9	8	4	24	

Table 7. Participants' competence comparison of participants with different background.

Items		Factors	
		Ages (median (Q1-Q3))	Years of service in malaria microscopy (median (Q1-Q3))
Participants' Competence of Malaria Microscopy	A(n=10)	35.0 (34.0–39.3)	9.0 (6.5–13.0)
	B(n=33)	35.0 (32.0–42.5)	8.0 (4.0–10.0)
	C(n=18)	33.0 (31.0–36.5)	3.0 (1.0–5.3)
	D(n=11)	36.0 (30.0–40.0)	2.0 (0.5–10.0)
Total		35.0 (32.0–40.0)	6.5 (2.0–10.0)
Correlation Coefficient(ρ)		0.2	0.4
Sig. (2-tailed)		$P>0.05$	$P<0.01$

Table 8. Relevance between participants' competence and their ages or years serving for malaria microscopy.

in the remaining courses. No statistically differences were found among the outcomes of participants enrolled in the first, third, fifth, and sixth courses (see Table 6).

Statistical analysis revealed that demographic variables such as age, workplace, educational background and gender did not affect participants' competence in malaria microscopy (see Tables 7 and 8). In contrast, the number of years of experience in malaria microscopy showed a moderate positive correlation with competence levels ($n=72$; $\rho=0.4$, $P<0.01$) (see Table 8). All 72 participants scored above the minimum threshold required for their respective certification levels in PD, PC, and SP.

Scores for SI improved significantly in the final test ($n=72$; 82.0 (Q1-Q3:74.0–88.0)) compared to the pre-test ($n=72$; 62.0 (Q1-Q3:50.0–77.0)) ($Z=-7.3$, $P<0.01$). Furthermore, 23 participants demonstrated a significant improvement in this competence following the NCAMM course (75.0 (Q1-Q3:67.0–82.0)) compared to WHO-ECAMM course both in the pre-test (88.0 (Q1-Q3:76.0–92.0)) and the final test (93.0(Q1-Q3:83.0–95.0)) (see Table 9).

Pre-assumed structure of human resource development of malaria microscopists in China

The spatial distribution patterns of malaria cases in China in 2023 and 2024 indicate that all provinces have reported occurrences^{5,6}. A majority of provinces (21–22 out of 31) reported cases in more than 60% of their sub-provincial regions, while nearly half of the provinces (14–16 out of 31) reported cases in fewer than 20% of their counties. Therefore, it is recommended that core groups composed of highly competent malaria microscopists be established at the national, provincial, and most sub-provincial levels. At the county level, staffing strategies may vary depending on the local malaria situation. The proposed human resource structure for malaria

Tests	No. of participants	Scores (median (Q1-Q3))	Wilcoxon-test	
			NCAMM- Final-test	ECAMM-Final test
NCAMM-Pre-test	72	62.0(50.0–77.0)	$Z=-7.3, P<0.01$	/
NCAMM-Final test	72	82.0(74.0–88.0)	/	/
NCAMM-Final test	23	75.0(67.0–82.0)	/	$Z=-3.9, P<0.01$
ECAMM- Pre-test	23	88.0(76.0–92.0)	$Z=-2.4, P<0.05$	$Z=-3.0, <0.01$
ECAMM-Final test	23	93.0(83.0–95.0)	/	/

Table 9. Comparison of participants' SI scores between different periods*. Notes: * 23 participants took part in both NCAMM and WHO-ECAMM successively. /Comparison was not conducted.



Fig. 1. Pre-assumed structure of human resource development of malaria microscopists in China.

microscopists includes three core groups operating at the national, sub-national (provincial), and sub-provincial levels. This structure suggests the application of four models for assessing microscopists' competence (see Fig. 1).

The national core group consists of microscopists employed in national and provincial laboratories. All members should currently hold a certification of Level 1 or Level 2 in the WHO-ECAMM courses. In provinces where malaria cases have been reported in five or more sub-provincial areas over the past three years, it is recommended that microscopists in the provincial core group be certified at least at Level A or B in the NCAMM courses. In provinces where malaria cases have been reported in zero to four sub-provincial areas during the same period, microscopists certified at Level A or B in the NCAMM courses are

considered acceptable. Alternatively, those who have been assessed as qualified malaria microscopists through other provincial competence assessment mechanisms (PCAMM) are also acceptable. The provincial core group is composed of microscopists working in provincial and sub-provincial laboratories.

At the county level, qualified malaria microscopists trained through PCAMM courses are essential in counties that have reported malaria cases in the past three years. In counties where no malaria cases have been reported for at least five consecutive years, greater emphasis should be placed on the microscopists' ability to prepare blood smears and maintain awareness for malaria case screening, rather than on the precise identification of parasite species. This objective can be achieved through Basic Training Courses (BTC) conducted by sub-provincial or provincial institutions. Ideally, the core group at the sub-provincial level should consist of microscopists who have been certified through either PCAMM or BTC training programs.

Discussion and conclusion

The WHO-ECAMM course in previous studies has demonstrated dual functions in both assessing and training microscopy skills¹⁴. Additional improvements in SI scores among the 23 participants who had also completed both the WHO-ECAMM course and NCAMM course verified it again. Among the four fundamental components of malaria microscopy, the scores on SI were found to have the most significant impact on determining participants' overall competence in the six NCAMM courses conducted in China. Similar to WHO-ECAMM courses, all 72 NCAMM participants showed improvement in their SI scores from the pre-test to the final test. Furthermore, participants in the 8th and 9th WHO-ECAMM courses who had less or no chances of reading slide films in routine work, but just experienced NCAMM course achieved nearly same assessment results (8 out of 12 participants were certified at 1 or 2 levels) with those who had more chances and/or had experienced WHO-ECAMM courses previously achieved in 7th and 10th WHO-ECAMM courses (9 out of 12 at 1 or 2 level), and likely better than those in 5th WHO-ECAMM who had some or more chances but never experienced NCAMM course achieved (6 out of 12 at 1 or 2 level)¹⁴. Therefore, the NCAMM model can serve as an effective tool for enhancing the competence of malaria microscopists. Basically, this capability enhancement should attribute to the repeated reading of sufficient smears in courses. This point is verified by the correlation analysis of data from the six NCAMM courses which revealed no significant relationship between participants' competence and factors such as institutional hierarchy, educational background, gender, or age, but the number of years of experience in malaria microscopy was identified as a key determinant of proficiency. Those results give more evidence to that malaria microscopy is a skill largely dependent on accumulated experience. Thus, to sustain the competence of certified microscopists, continuous supportive activities, such as certain amount of smear reading in work, participating in proficiency testing system and being reassessed at least every 3 years are required.

Since NCAMM courses conducted in China demonstrate efficacy as both an evaluation system and in some way, a refresher training model, they can be and are expected to be widely implemented at both national and sub-national levels to enhance the human resource capacity of microscopists. Furthermore, the model may serve as a reference for other countries or regions that are either historically malaria-free or have achieved malaria-free certification. Additionally, several recommendations can be made that differ from those of the WHO-ECAMM courses^{10,11}.

First, new criteria for SP were developed based on previous national and WHO guidelines^{13–16}, which were issued in 2019¹⁵. There is a consensus that blood smears with high quality is essential to accurate diagnosis of malaria, while those with low quality likely lead to misdiagnosis or missed diagnosis^{17–20}. Because the certified participants were expected to act as comprehensive experts and trainers, the SP skill levels of participants were assessed in the NCAMM course which were not in the WHO-ECAMM course. However, no internationally recognized standards for evaluating SP competence were on hand which could be applied directly. The Chinese model used in the National Technical Competition for Diagnosis of Parasitic Diseases is relatively subjective due to time constraints, as SP competence is primarily assessed based on the appearance of blood smears¹⁴, using indicators such as “correct size,” “somewhat incorrect size,” and “incorrect size.” Drawing from the initial version and experiences gained during NCAMM implementation, a total of 13 criteria items were ultimately included. Among these, items 2 (diameter of thick film is 10–12 mm, even, and more than 90% intact), 3 (thick film has adequate thickness, with an average of 10–20 white blood cells per field), and 8 (size of thin film is adequate; length and width are both ≥ 20 mm) were revised, while item 4 (position of thick film is correct, with a distance from the center of the thick film to the nearest short edge ≥ 30 mm) was newly added compared to the first version¹⁵. These criteria can also be effectively applied in quality assurance (QA) programs.

However, participants' scores on SP assessment from the pre- to the final-tests are not presented here. Based on observations, most participants were able to produce 100% qualified recordings, as additional skill training and practice prior to the final-test improved and ensured their competence.

Secondly, within the NCAMM course, the criteria for assessing competence in parasite counting (PC) were based on the WHO/WPRO/RITM External Quality Assessment (EQA) Program for Malaria Microscopy, which differ from those used in the WHO-ECAMM framework^{10,11}. According to the WHO-ECAMM standards, participants receive full credit if their count falls within $\pm 25\%$ of the reference value; otherwise, no points are awarded. PC is widely recognized as the most challenging component of malaria microscopy. Therefore, the NCAMM program introduced a modified scoring criterion, whereby participants receive one point if their count lies between 25% and 50% of the reference count. This adjustment is intended to encourage participants to improve their ability to recognize and identify parasites, thereby enhancing their overall proficiency in PC.

Finally, since the integration of SP assessment into the NCAMM curriculum, the original schedule based on the WHO-ECAMM framework proved insufficient for maintaining a balanced approach between theoretical instruction and practical skill development. To resolve this issue, theoretical sessions and skill-based presentations were strategically moved to the end of the agenda. This adjustment offers an additional advantage:

facilitators can gain preliminary insights into participants' strengths and weaknesses during earlier activities, enabling them to tailor and emphasize key content in subsequent presentations. As a result, participants benefit from a more conducive learning environment, allowing them to consolidate knowledge and skills after a full day of hands-on practice.

Based on six WHO-ECAMM courses, the national core group of malaria microscopists was re-affirmed. Although level-1 certified microscopists from eight provinces were not reassessed in the past three years, their competence remains credible, as they have consistently maintained their roles in malaria microscopy since certification, both during and after the malaria elimination phase. The assessment results of those who participated in the WHO-ECAMM courses on multiple occasions from 2012 to 2024 further support this conclusion.

To ensure the quality assurance (QA) of malaria diagnosis, the National Reference Laboratory Network for Malaria Diagnosis (NRLNMD) was established during the elimination phase in China¹⁶. Certified microscopists in WHO-ECAMM courses served as the core workforce responsible for operating the NRLNMD and implementing QA activities. For instance, they were entrusted with the final responsibility for species identification of malaria parasites, participated in the drafting of national and provincial microscopy standards, trained fresh microscopists, and contributed to various other malaria control initiatives^{15,21–30}. The NCAMM course was developed and implemented in China as a standardized model to assess the competence of microscopists in provincial core groups. Provincial-level personnel certified at level A or B were also authorized to make final species identification decisions. It was expected that all members of these core groups would support the development of microscopist teams at the county and township levels nationwide, thereby facilitating the expansion of the NRLNMD and the implementation of QA activities.

Certified microscopists through the WHO-ECAMM and NCAMM programs have made significant contributions and instilled confidence in the QA system. Their achievements have inspired the concept of defining and evaluating the competence of malaria microscopists working at peripheral levels. The framework for human resource development of malaria microscopists presented in this file offers programmatic guidance to this concept. However, unified standards and practical procedures for certifying microscopists at sub-provincial and county levels remain under development. In fact, various PCAMM courses have been implemented across 31 provinces to train and assess microscopists, although few results have been reported^{21,22}. It is evident that uniform cutoff standards are needed to validate these training programs and ensure that certified microscopists are capable of detecting and diagnosing malaria as early and accurately as possible. A prototype of harmonized cutoff standards has therefore been proposed for discussion, based on the minimum competence levels for peripheral-level microscopists outlined in the WHO guidelines¹¹.

The concept of BTC was first introduced in China. Given the context of a low incidence rate, this initiative is based on the establishment of national and provincial core teams of highly competent microscopists, as well as the feasibility of rapid, remote malaria diagnosis through internet-based sharing using computers or mobile devices. Under such situation, a microscopist, who can distinguish unusual exogenous organisms in peripheral blood, with awareness and ability to screen malaria cases and to prepare blood films is enough to surveil malaria. The training costs is much less than training him/her to be an expert in malaria microscopy. However, the implementation schedule and evaluation criteria must be finalized following comprehensive field investigations, practical trials, and discussions. This project has been incorporated into the routine work plan of NIPD in recent years.

The NRLNMD has played a crucial role in ensuring the accuracy and reliability of Plasmodium diagnosis in healthcare facilities^{23–27}. In the near future, with continued development of human resources and the training of qualified microscopists, an expanded NRLNMD is expected to further contribute to achieving the “Three Early” of malaria prevention and control and high-quality execution of the NSP-2025. Meanwhile, targeted activities within NRLNMD and the QA system can be designed in response to fluctuations in the malaria situation and human resource availability. Furthermore, the performance monitoring and active participation in NRLNMD and QA activities serve as effective strategies for sustaining and enhancing microscopists' diagnostic competence.

Limitation

The limited sample size is the most obvious but inevitable limitation of this study. Organizing training courses is generally resource-intensive, requiring substantial time, effort, and financial investment. As a result, data were collected from only six WHO-ECAMM courses and six NCAMM courses in total.

Data availability

The data and materials used in this study can be obtained by contacting Dr. Mei Li at li_mei76@163.com.

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Author contributions

Li M, as the initiator of the NCAMM courses in China, has organized seven WHO-ECAMM courses, established the assessment criteria, designed and conducted eleven NCAMM courses, processed all samples, analyzed the data, and drafted the manuscript. Liu H and Wang ZY assisted in finalizing the assessment criteria and course design and participated in two to three courses as facilitators. Wang YB, Yan G, Zhou RM, Deng Y, Liu H and Deng Y served as organizers of NCAMM courses in province 1, 2 and 3 respectively, and provided valuable suggestions for the implementation of NCAMM. Li M and Xia ZG served as organizers of the first and sixth NCAMM courses. Xia ZG also dispatched facilitators to the six NCAMM courses. Wang SQ and Dai YQ assisted in the sixth NCAMM course. Zhou XN and Li SZ were responsible for signing participants' certificates. Li SZ supported the revision and publication of this manuscript. All authors reviewed and approved the final version of the manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

Ethics statement

This study was reviewed and approved by the Ethics Committee of the National Institute of Parasitic Diseases,

China CDC. All participants in this study provided informed consent to participate. we confirm that consent was obtained from all human participants involved in the research. This declaration has been clearly included in the revised manuscript.

Additional information

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