Original Article

Epidemiological Characteristics of Imported and Locally-acquired Malaria in Singapore

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Abstract

Introduction: The objective of the study was to determine the trend of malaria, the epidemiological characteristics, the frequency of local transmission and the preventive and control measures taken. Materials and Methods: We analysed the epidemiological records of all reported malaria cases maintained by the Communicable Diseases Division, Ministry of Health, from 1983 to 2007 and the *Anopheles* vector surveillance data collected by the National Environment Agency during the same period. Results: The annual incidence of reported malaria ranged from 2.9 to 11.1 per 100,000 population, with a sharp decline observed after 1997. There were 38 deaths, 92.1% due to falciparum malaria and 7.9% due to vivax malaria. Of the reported cases, 91.4% to 98.3% were imported, with about 90% originating from Southeast Asia and the Indian subcontinent. Among the various population groups with imported malaria, the proportion of cases involving work permit/employment pass holders had increased, while that of local residents had decreased. Between 74.8% and 95.1% of the local residents with imported malaria did not take personal chemoprophylaxis when they travelled overseas. Despite the extremely low *Anopheles* vector population, a total of 29 local outbreaks involving 196 cases occurred. Most of the larger outbreaks could be traced to foreign workers with imported relapsing vivax malaria and who did not seek medical treatment early. One of the outbreaks of 3 cases in 2007 was caused by *Plasmodium knowlesi,* a newly recognised simian malaria which was probably acquired in a forested area where long-tail macaques had been sighted. Conclusions: Singapore remains both vulnerable and receptive to the reintroduction of malaria and a high level of vigilance should be maintained indefinitely to prevent the re-establishment of endemicity. Medical practitioners should highlight the risk of malaria to travellers visiting endemic areas and also consider the possibility of simian malaria in a patient who has no recent travel history and presenting with daily fever spikes and with malaria parasite morphologically similar to that of *P. malariae*.

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Key words: *Anopheles* mosquitoes, Foreign workers, Outbreaks, Simian malaria

Introduction

Malaria used to be endemic in Singapore. In the early 1900s, almost 3000 malaria-related deaths were reported annually. Malaria control started in 1911 with the construction of a comprehensive drainage system. Together with an anti-larval oiling programme, malaria was rapidly put under control. Unfortunately, these measures broke down during World War II resulting in a resurgence of malaria. After the war, malaria was once again brought under control and it was believed that local transmission of malaria had ceased.[1] In 1964, a local outbreak of 29 cases occurred at Fuyong estate.[2] This led to a comprehensive review of the existing malaria control strategies. In the 1970s, rapid and massive land development and the influx of large numbers of foreign workers from malarious countries provided favourable epidemiological conditions for local transmission of malaria with a very large outbreak of 82 cases reported at Whampoa-Kallang in 1974 to 1975.[3] Consequently, epidemiological and vector surveillance activities were further strengthened. In November 1982, Singapore was certified malaria-free by the World Health Organization (WHO). This milestone was achieved as WHO was confident that Singapore's comprehensive health service networks in the urban settings with its effective malaria

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vigilance mechanism would be adequate to prevent the re-establishment of endemic malaria in the infinite future.[4]

We carried out a review of the malaria situation in Singapore from 1983 to 2007 to determine the trend, the epidemiological characteristics, the frequency of local transmission and the preventive and control measures taken.

Materials and Methods

The Ministry of Health (MOH) is responsible for case surveillance and epidemiological investigation of malaria in Singapore, while the surveillance and control of *Anopheles* mosquitoes are undertaken by the National Environment Agency (NEA). To facilitate case surveillance, the Infectious Diseases Act requires medical practitioners to notify all malaria cases and deaths to MOH within 24 hours of diagnosis. This can be done either through facsimile or via a dedicated website. Epidemiological information required for each notification includes age, unique identification number, date of birth, ethnic group, gender, residential and workplace or school addresses, date of onset of symptoms, date of diagnosis and whether the diagnosis was clinical or confirmed by laboratory tests. MOH provided the clinical criteria for the diagnosis of malaria, and the recommended laboratory tests and clinical management in a document that was made available to all medical practitioners.[5] For vector surveillance, a dedicated team of NEA officers is routinely deployed to search for *Anopheles* vectors in areas with known past local transmission or with environmental conditions conducive for such vectors to breed. All larvae and pupae detected are collected and identified at the Environmental Health Institute, NEA. The vector breeding sites are displayed in the NEA's Geographical Information System (GIS).

Based on epidemiological information provided in the notification, supplemented by telephone interview and field investigation, each malaria case was classified into various categories in accordance to the WHO's definitions as follow: [6]

Imported: as shown by tracing the case to its origin in a malarious area outside Singapore

Introduced: directly secondary to a known imported case

Relapsing: a relapse of a pre-existing infection as shown by the history of the case and the absence of any associated cases in the neighbourhood of its origin

Induced: as shown by its relation to a blood transfusion with an appropriate interval, or to another form of parenteral inoculation to which infection could be properly attributed

Indigenous: a malaria infection which has been proved or cannot be disproved to be due to recent local transmission

Cryptic: isolated and not associated with secondary cases, as determined through appropriate epidemiological investigation, including mass blood survey after the expiry of the incubation interval

Epidemiological investigations which included active case detection and fever and blood surveys were immediately conducted as soon as a notified case could not be classified as imported. NEA was alerted to carry out *Anopheles* surveillance and "search and destroy" operations. An outbreak was defined as a cluster of two or more epidemiologically related cases linked by place of residence, work or school within 800 m of each other and within one incubation period of the malaria species involved.

All physician-diagnosed, laboratory-confirmed cases and deaths of malaria notified between 1983 and 2007 were included in the study. The data was obtained from the records maintained by the Communicable Diseases Division, MOH. Deaths from malaria were also obtained from the Registry of Births and Deaths. For the calculation of the various incidence rates, the denominators were the estimated mid-year population of the corresponding years from the Department of Statistics.

Results

Epidemiological Situation

The annual incidence rate of reported malaria ranged from 5.9 to 11.1 per 100,000 population during the period 1983 to 1997. This was followed by a sharp decline to 2.9 per 100,000 population in 2003 and thereafter maintained at between 3.3 and 3.9 per 100,000 population (Fig. 1).

Most of the infections were caused by *P. vivax* (66.0% to 78.4%), followed by *P. falciparum* (19.2-31.0%). Infections by *P. malariae* were uncommon (Table 1). *P. knowlesi* infections were first diagnosed in 3 cases initially thought to be due to *P. malariae* in 2007.

All age groups were affected with the highest mean annual age-specific incidence rate in the 25 to 34 year age group (Table 2). There was a male predominance with males outnumbering females by 4.2 times. The majority of the notified cases were foreigners who comprised 53.3% to 71.8% of the reported cases. Among the 3 major ethnic groups of local residents, Indians had the highest mean annual incidence rate from 1983 to 1997, but this was overtaken by Malays from 1998 onwards (Table 3).

Based on the travel history, majority of the reported cases were imported (91.4% to 98.3%) (Table 4). Most of the imported cases originated from Southeast Asia, mostly from Indonesia, and the Indian subcontinent. These 2 regions accounted for about 90% of the imported cases (Table 5). Based on the various population groups with imported malaria, there has been a decreasing proportion of cases involving local residents. On the other hand, the proportion of work permit/employment pass holders with

Table 1. Mean Annual Distribution (%) of Malaria Parasite Species, 1983-2007

Parasite species	1983-1987 (n = 923)	1988-1992 (n = 1135)	1993-1997 (n = 1732)	1998-2002 (n = 1391)	2003-2007* (n = 768)
Plasmodium vivax (P.v.)	72.5	68.5	78.4	66.0	67.2
Plasmodium falciparum (P.f.)	24.6	29.2	19.2	31.0	29.6
Mixed (P.v. & P.f.)	2.6	2.1	2.2	2.9	1.9
Mixed (P.v. & P.m.)	0.0	0.0	0.0	0.1	0.1
Plasmodium malariae (P.m.)	0.3	0.2	0.2	0.1	1.2
Total	100.0	100.0	100.0	100.0	100.0

* Exclude 3 cases of *P. knowlesi* infection in 2007

Table 2. Mean Annual Age-Specific Incidence Rate Per 100,000 Population of Reported Malaria Cases, 1983-2007

Age group (y)	1983-1987 (n = 923)	1988-1992 (n = 1135)	1993-1997 (n = 1732)	1998-2002 (n = 1391)	2003-2007* (n = 768)
0-4	2.4 (2.8)	1.5 (1.5)	1.3 (1.0)	2.2 (1.9)	1.1 (1.5)
5-14	1.7 (3.9)	2.1 (3.9)	2.3 (2.9)	2.9 (4.9)	1.2 (3.9)
15-24	8.1 (25.3)	7.6 (19.0)	14.0 (23.6)	8.7 (18.8)	5.0 (21.3)
25-34	9.4 (30.7)	10.4 (31.8)	17.2 (39.4)	10.4 (32.3)	5.6 (31.9)
35-44	8.2 (16.6)	10.4 (23.0)	9.2 (17.3)	6.9 (18.9)	3.2 (15.9)
45-54	8.9 (11.4)	10.1 (11.9)	8.1 (8.5)	6.4 (12.6)	3.5 (14.0)
55+	5.7 (9.3)	5.7 (8.9)	5.8 (7.3)	5.5 (10.6)	2.6 (11.5)
Total	6.8 (100.0)	7.5 (100.0)	9.8 (100.0)	6.9 (100.0)	3.6 (100.0)

* Exclude 3 cases of *P. knowlesi* infection in 2007
Numbers in brackets refer to percentage distribution

Table 3. Mean Annual Ethnic-Specific Incidence Rates Per 100,000 Population of Reported Malaria Cases, 1983-2007*

Ethnic group	1983-1987 (n = 923)	1988-1992 (n = 1135)	1993-1997 (n = 1732)	1998-2002 (n = 1391)	2003-2007* (n = 768)
Residents					
Chinese	2.1 (22.2)	2.4 (22.3)	2.1 (14.2)	1.7 (15.2)	0.8 (13.8)
Malay	2.0 (3.8)	5.0 (8.4)	5.0 (5.6)	7.1 (11.1)	3.0 (9.5)
Indian	22.4 (20.0)	11.8 (10.0)	9.8 (6.2)	4.5 (4.2)	2.8 (5.3)
Others	4.7 (0.7)	8.6 (1.1)	20.5 (2.2)	6.9 (1.2)	3.6 (1.6)
Foreigners	39.2 (53.3)	42.5 (58.2)	47.4 (71.8)	24.7 (68.3)	12.9 (69.8)
Total	6.8 (100.0)	7.5 (100.0)	9.8 (100.0)	6.9 (100.0)	3.6 (100.0)

* Exclude 3 cases of *P. knowlesi* infection in 2007
Numbers in brackets refer to percentage distribution

imported malaria has increased. There was also a rising proportion of foreigners seeking medical treatment in Singapore and diagnosed to have malaria (Fig. 2). Among the local residents, a high proportion (74.8% to 95.1%) did not take personal chemoprophylaxis while they were away in malarious areas. Moreover, the proportion of residents taking the recommended chemoprophylaxis has steadily declined from 18.8% to 0.5% (Fig. 3).

The majority of the imported cases were detected within 2 weeks of entry into Singapore. Beyond 6 weeks, it was found that almost all of the cases were due to relapsing *P. vivax* infection.

A total of 38 deaths from malaria were reported during the period of review. No death was reported since 2002. Of these deaths, 35 (92.1%) were due to falciparum malaria and, despite the relatively benign nature of *P. vivax* infections, 3 (7.9%) were due to vivax malaria. The causes of deaths included cerebral malaria, disseminated intravascular

Table 4. Classification (%) of Reported Malaria Cases, 1983-2007

Classification	1983-1987 (n = 923)	1988-1992 (n = 1135)	1993-1997 (n = 1732)	1998-2002 (n = 1391)	2003-2007* (n = 768)
Imported†	97.8	98.3	91.4	96.3	96.7
Introduced	2.2	0.6	4.1	2.1	1.2
Indigenous	0.0	0.0	3.4	0.1	1.6
Cryptic	0.0	0.0	1.1	1.5	0.5
Induced	0.0	0.0	0.0	0.0	0.0
Relapsing	0.0	1.1	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0

* Exclude 3 cases of *P. knowlesi* infection in 2007
† Include imported relapsing cases

Table 5. Mean Annual Distribution (%) of Imported Malaria Cases by Country of Origin, 1983-2007

Countries	1983-1987 (n = 903)	1988-1992 (n = 1116)	1993-1997 (n = 1575)	1998-2002 (n = 1331)	2003-2007 (n = 742)
Southeast Asia					
Indonesia	26.4	42.0	22.0	51.1	38.9
Malaysia	6.8	7.5	5.0	5.3	3.9
Thailand	13.9	6.5	5.5	2.5	1.6
Myanmar	0.6	2.3	2.7	3.4	3.7
Indian Subcontinent					
Bangladesh	0.7	1.4	7.7	1.3	0.3
India	41.8	28.3	47.9	27.2	38.5
Other Asian countries					
Papua New Guinea	2.6	2.9	1.6	1.3	1.8
Africa	1.1	2.1	2.8	5.8	8.1
Others	6.1	7.0	4.8	2.1	3.2
Total	100.0	100.0	100.0	100.0	100.0

coagulation, hepatic failure, respiratory distress syndrome, multi-organ failure, pulmonary oedema, bronchopneumonia and, acute renal failure. The last 3 complications were implicated in the deaths due to vivax malaria.

Local Malaria Outbreaks

A total of 29 local outbreaks involving 196 cases were reported between 1983 and 2007 (Fig. 1 and Table 6). The main epidemiological features of a few selected outbreaks, to demonstrate the importance of early recognition and outbreak control, are highlighted below.

(i) Punggol Point

The outbreak was initiated by 2 Punggol residents, both aged 71 years, who had recently returned to Singapore after a 9-month social visit to India. One of them had had a previous attack of malaria. Although they suffered from non-specific complaints after their return to Singapore, they self-medicated and did not seek medical treatment until they were quite ill with high fever. By the time malaria was confirmed, local transmission had already occurred, as the vector, *A. sundaicus*, was present in the area. These 2 imported cases gave rise to a crop of 12 cases (introduced malaria) and another crop of 15 cases (indigenous malaria) during the period from 10 April to 15 May 1993. Of these cases, 21 were residents from other parts of Singapore. The chain of transmission was interrupted within 3 weeks after the outbreak was alerted.[7]

(ii) Tanjong Rhu/East Coast Park

The outbreak was first identified among a group of foreign workers living and working at Tanjong Rhu which was undergoing rapid and massive land reclamation and development. Two of the workers with a past history of

Table 6. Main Epidemiological Features of Local Malaria Outbreaks in Singapore, 1983-2007

Period	Locality	Number of cases	Vector found	Parasite species	Remarks
June 1983	Pulau Bukom	2	No vectors found	*P. falciparum*	All the 758 blood films collected were negative for malaria parasites.
May 1984	Clementi West	3	No vectors found	*P. falciparum*	No malaria parasites detected in the 1870 blood films obtained from local residents and foreigners.
June-December 1986	Pulau Tekong	7	*A. sundaicus*	*P. vivax*	None of the 27 *A. sundaicus* adults caught infected with sporozoites
January-March 1987	Pulau Tekong	4	*A. sundaicus*	*P. vivax*	Twenty *A. sundaicus* breeding sites detected and 20 adults trapped. All 260 foreign workers were negative for malaria parasites.
19 April-28 May 1993	Punggol Point[7]	27	*A. sundaicus*	*P. vivax*	Outbreak initiated by 2 elderly local residents who contracted malaria in India and did not seek treatment early. No mosquitoes infected with sporozoites.
4 October 1993-3 January 1994	Tanjong Rhu/ East Coast[8]	43	*A. sundaicus*	*P. vivax*	Outbreak caused by the introduction of 2 imported cases of relapsing vivax malaria among foreign workers. No *Anopheles* larvae detected and only 1 non-infected female *A. sundaicus* adult caught.
20 May-6 June 1996	Pulau Tekong	5	*A. sundaicus*	*P. falciparum*	All were national servicemen.
24-25 May 1996	St John's Island	2	No vectors found	*P. falciparum*	Both were secondary school students.
12-23 June 1996	Dairy Farm[9]	19	*A. maculatus*	*P. vivax*	Index cases among foreign workers with imported relapsing vivax malaria. Two local residents infected.
18-23 June 1996	Upper Changi Road	3	No vectors found	*P. vivax*	Two national servicemen and 1 drug rehabilitation inmate.
18-26 June 1996	East Coast Park	4	No vectors found	*P. falciparum* and *P. vivax*	Visitors to the beach.
24 June-2 July 1996	Sentosa Island	2	No vectors found	*P. falciparum*	One foreign worker and 1 visitor.
3-5 October 1996	Fajar Road	2	*A. maculatus*	*P. falciparum*	Both were foreign workers living and working there.
June 1997	Pulau Ubin	2	No vectors found	*P. vivax*	Secondary school students attending Outward Bound School.
3-5 July 1997	Sisters' Islands	3	No vectors found	*P. falciparum*	All were undergraduates.
9-10 July 1997	Pulau Semakau/ Pulau Seking	2	No vectors found	*P. falciparum*	Both were foreign workers residing and working in the islands.
18-29 July 1997	Pulau Tekong	8	No vectors found	*P. vivax* and *P. falciparum*	Three national servicemen and 5 Gurkha policemen.
12-13 September 1997	Institution at Moon Crescent, Changi	8	No vectors found	*P. vivax*	All were inmates. No secondary transmission occurred. No malaria parasite detected in the 2679 blood films of asymptomatic inmates, staff and foreign construction workers.
16-17 September 1997	Jalan Sempadan	2	No vectors found	*P. falciparum*	Both were foreign workers residing and working there.
5 June-31 August1998	Pulau Tekong	6	*A. sundaicus*	*P. falciparum*	Four national servicemen and 2 Gurkha policemen.
3-5 December 1998	Pulau Tekong	2	*A. sundaicus*	*P. vivax*	Both were national servicemen.
17 December 1998-27 January 1999	Mandai[10]	9	*A. maculatus*	*P. vivax*	All were foreign workers. Outbreak did not spread to local residents.
10-15 May 1999	Pulau Tekong	2	*A. sundaicus*	*P. vivax*	Both were foreign workers.
28 Feb-13 March 2001	Lim Chu Kang	3	*A. sundaicus*	*P. falciparum* and *P. vivax*	Two national servicemen and 1 foreign worker. All the 922 blood films from local residents and foreign workers were negative for malaria parasites.

Table 6. Contd.

Period	Locality	Number of cases	Vector found	Parasite species	Remarks
18 June 2001	Upper Changi Coast Road East[11]	3	No vectors found	*P. falciparum*	No secondary transmission occurred. Blood films from 714 local residents and foreigners were negative for malaria parasites. A 71-year-old woman died of renal failure and disseminated intravascular coagulation.
July-August 2003	Pulau Tekong	5	*A. sundaicus*	*P. vivax*	Outbreak precipitated by an imported case among Gurkha contingent with relapsing vivax malaria.
March-September 2006	Jurong Island/ Pulau Busing[12]	13	No vectors found	*P. vivax*	All were foreign workers. Index case with relapsing vivax malaria.
April-May 2007	Lim Chu Kang[13]	3	Studies in progress to determine the vectors	*P. knowlesi*	National servicemen training in a forested area where long-tail macaques were sighted.
June 2007	Redhill	2	No vectors found	*P. vivax*	Both were local residents. 170 blood films from foreign workers were all negative for malaria parasites.

malaria in their hometown had a relapse after arrival in Singapore, and one of them did not seek medical treatment until 17 days after the onset of symptoms. Transmission of infection was initially confined to Tanjong Rhu, but it spread rapidly to East Coast Park. A total of 43 cases of vivax malaria were confirmed between 4 October 1993 and 3 January 1994. Except for 8 foreign workers, all the other reported cases were local residents who stayed in other parts of Singapore and had visited the area during the evenings for fishing, jogging and other recreational activities prior to the onset of symptoms. Despite extensive vector surveillance, no *A. sundaicus* larvae were detected although the reclaimed land area could provide suitable habitats for the breeding of this vector. Of the 4611 adult mosquitoes trapped in the outbreak area, only one was identified as *A. sundaicus* but it was not infected with malaria sporozoites. The delay in breaking the chain of transmission resulted in the generation of 37 indigenous malaria cases.[8]

(iii) Dairy Farm

The index cases in this outbreak were traced to 2 foreign workers living and working at Dairy Farm, a known malaria receptive area. Both had a relapse of malaria within 7 months of arrival in Singapore. When other foreign workers in the area were subsequently confirmed to have vivax malaria, local transmission was suspected since all these cases did not have a past history of malaria and they had not travelled out of Singapore. Epidemic control measures were immediately implemented. The chain of transmission was rapidly interrupted within a week and only one crop of introduced cases, secondary to the two imported cases, occurred. *A. maculatus* larvae were detected in several sites, but no adult vectors were caught. A total of 19 vivax malaria cases were reported during the 2-week period between 12 June and 23 June 1996. Of these, 2 were local residents staying in the condominium nearby, and the rest were foreign workers.[9]

(iv) Mandai

The index case of this outbreak was a foreign worker who had a past history of malaria in his hometown. He stayed near a granite quarry in Mandai and had a persistent fever after arrival in Singapore but did not seek medical treatment until 9 months later. As *A. maculatus* was present in the area, the infection was transmitted to 6 other foreign workers within a 2 km radius during the period 14 to 22 December 1998. Despite prompt implementation of epidemic vector control measures and mass blood surveys, another 2 foreign workers came down with malaria between 26 and 27 January 1999. These last 2 cases had been repeatedly screened but continued to be negative for malaria parasites until fever developed.[10]

(v) Jurong Island/Pulau Busing

The index case of this outbreak was an Indian foreign worker who was diagnosed to have relapsing vivax malaria 7 months after arriving in Singapore. When cases continued to be reported among other foreigners working in these offshore islands, all with no recent travel history out of Singapore and with no past malaria attacks in their hometowns, local transmission was suspected. A total of 12 other foreign workers were subsequently confirmed to be infected with *P. vivax* from April to September 2006. Despite extensive vector surveillance, no *Anopheles* larval breeding habitats were detected and no adult vectors were caught.[12]

(vi) Lim Chu Kang Road

On 28 April 2007, a 20-year-old national serviceman sought medical treatment for fever, myalgia, anorexia, nausea and occasional vomiting. Prior to his onset of illness, he had trained in a forested area inhabited by the long-tail macaques *(M. fascicularis)* in Lim Chu Kang. Microscopy of the blood film showed morphological features of *P. malariae*. However, as the clinical features with daily fever spikes and marked symptoms were not consistent with *P. malariae*

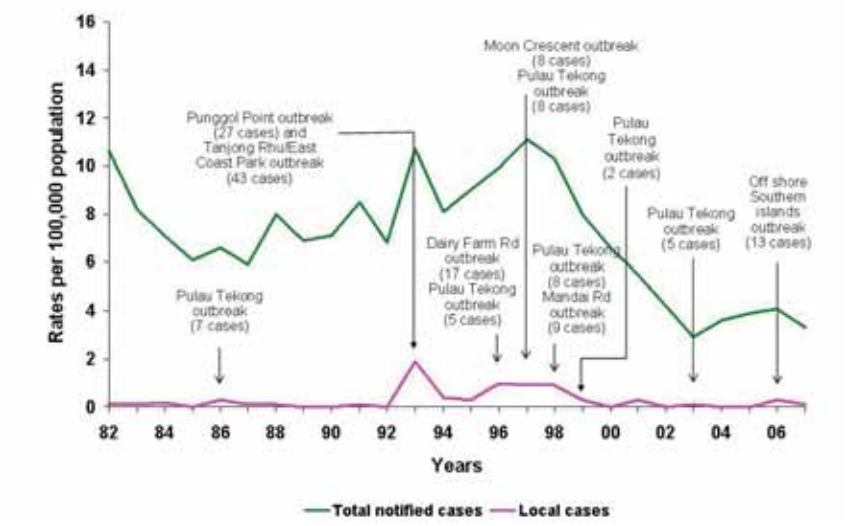

Fig. 1. Incidence (per 100,000 population) of total reported cases and local cases 1982*-2007.
* Singapore certified free from malaria by WHO in 1982

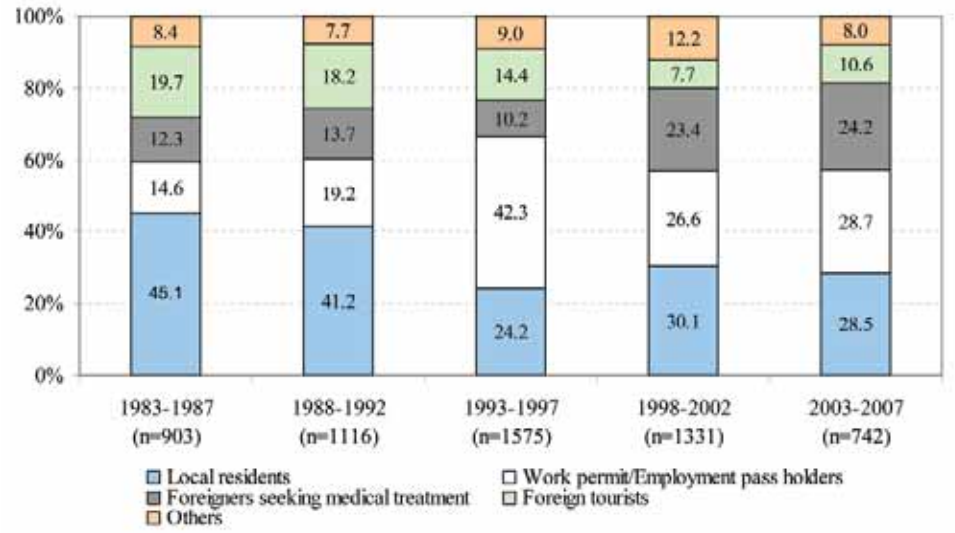

Fig. 2. Mean annual distribution (%) of imported malaria cases by various population groups, 1983-2007.

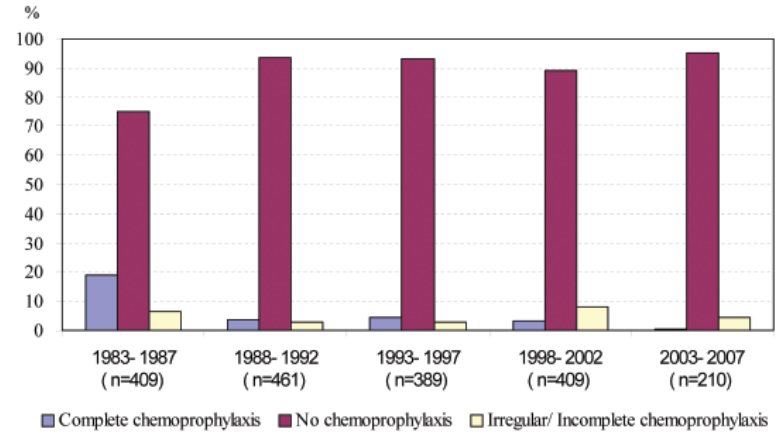

Fig. 3. Mean distribution (%) of chemoprophylaxis history for local residents who contracted malaria overseas, 1983-2007.

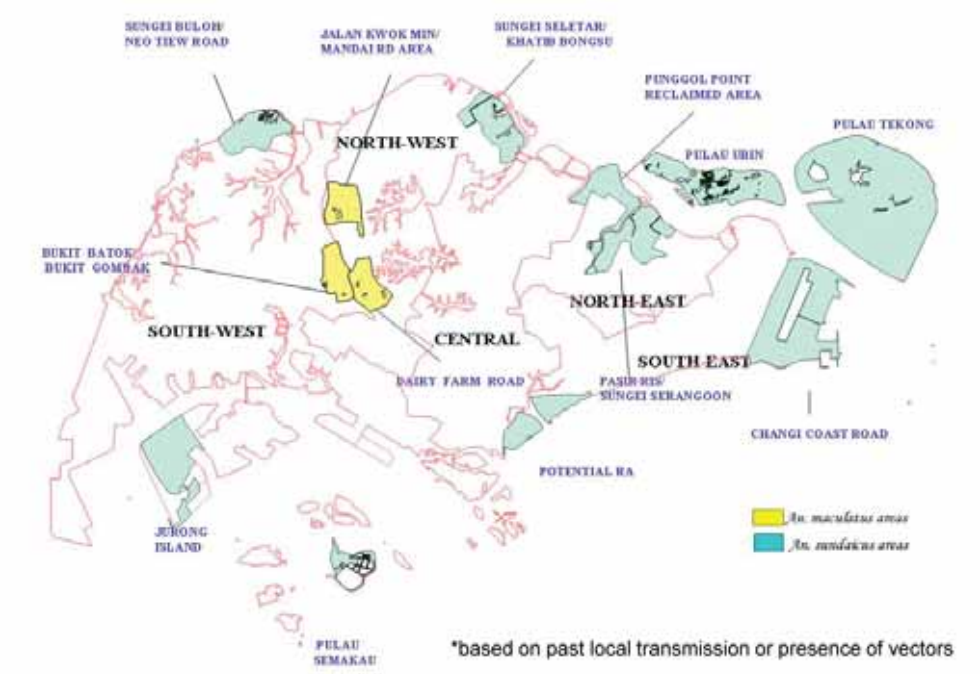

Fig. 4. Potential malaria receptive areas in Singapore and off-shore Islands, 2008.

infection, further investigation was conducted to confirm the aetiology. Polymerase chain reaction (PCR) studies using *Plasmodium knowlesi*-specific primers, followed by sequencing and phylogenetic analyses confirmed *P. knowlesi* infection. Epidemiological investigations based on his movement history showed that the infection was most probably acquired in the forested area at Lim Chu Kang.[13] Another 2 soldiers from the same army camp with similar clinical features and movement history were also confirmed to be infected with the same simian malaria parasite. It was the clinical acumen of the infectious diseases physicians and the availability of diagnostic tests that had enabled this cluster of cases caused by an emerging zoonotic disease to be identified. Studies are in progress to determine the vectors and reservoir of infection.[13]

Discussion

The incidence of imported malaria had declined over the last decade with a corresponding reduction in the incidence of locally acquired malaria. The main population group which showed the largest decline in imported malaria was work permit/ employment pass holders who constituted 42.3% of the imported cases in 1993 to 1997, but dropped to 26.6% to 28.7% in subsequent years. This could be attributed to the introduction of compulsory screening of this group of foreigners for malaria parasites by MOH on 1 Jan 1997 at the point of application of work permit/employment pass and at renewal. Those tested positive for malaria parasites would not be permitted to work in Singapore until they were treated and medically certified malaria-free. However, the screening programme could not completely eliminate the importation of vivax malaria by asymptomatic work permit/ employment pass holders as blood films could be repeatedly negative for malaria parasites during the exo-erythrocytic phase of the life cycle. Based on our experience, the pick-up rate of malaria parasites among asymptomatic foreign workers was extremely low, at around 0.1%.[14]

Relapsing vivax malaria among foreign workers deployed in malaria-receptive areas where *Anopheles* vectors are present continues to pose a major challenge to the prevention of malaria outbreaks in Singapore. Several large local outbreaks; e.g. at Tanjong Rhu/East Coast Park, Dairy Farm, Mandai and Jurong Island/Pulau Busing[8-10,12] were initiated by these foreign workers. As these workers are highly mobile and paid daily wages for the work done, they tend not to report sick unless seriously ill. By that time, transmission would have already occurred. Imported vivax malaria among foreign workers were known to relapse as long as 30 weeks after arrival in Singapore.[4]

To tackle this constant threat of malaria transmission which could occur even with an extremely low vector population, the NEA has put in place an integrated vector surveillance and control programme comprising environmental management and source reduction.

For environmental management of vector breeding sites, surface drains and subsoil pipes are laid in all areas favourable for the propagation of *A. maculatus*; specifically,

seepage water of hilly terrain. In major water development projects involving the construction of dams across tidal rivers in the Western Catchment area and Seletar River[15] the salinity of water was closely monitored. When the salinity had reached a level suitable for the propagation of *A. sundaicus* vectors, a brackish water breeder, the frequency of anti-larval oiling was intensified. These vector control measures were also adopted for the recently completed Marina barrage, a dam built across Marina channel in the city area. As a result, no outbreaks had been reported in all these water development sites

Whenever *Anopheles* breeding sites are detected, NEA will carry out larviciding with insecticides and source reduction to target at the immature stages of the vector. In addition, intensive thermal fogging and residual spraying will be conducted to kill any adult mosquito that may be present in the vicinity. Light trapping and human baiting with double netting will also be initiated to assess the effectiveness of the vector control measures implemented.

This integrated vector surveillance and control programme has successfully limited the number of *Anopheles* mosquito breeding sites to only a few areas (designated malaria receptive areas) throughout the island (Fig. 4). As an additional preventive measure, the management of any worksite situated in these areas is required to carry out weekly larvicidal oiling/spraying (with anti-malarial oil) and night fogging (with pirimiphos-methyl), and monthly residual-spraying (with malathion) of both the interior and exterior walls of all *bangsals* (workers' living quarters) and site offices. MOH also conducts *ad hoc* blood screening on all foreign workers living or working there. If any worker at the worksite is suspected or confirmed to have acquired malaria locally, the employer is required to further step up vector control operations and to provide insect repellents or mosquito nets for all the workers who stay within the premises at night. Chemoprophylaxis will also be recommended if necessary.

Among local residents with imported malaria, more than 90% of them travelling to the endemic countries for social visit, business or recreation did not take chemoprophylaxis. This could be attributed to the low perception of risk when travelling overseas.[16] In studies done elsewhere, poor compliance was attributed to various reasons such as misconception that malaria is a trivial illness, inaccurate advice from fellow travellers and tour agencies, and inadequacy of other personal protection measures.[17-20] Health education to increase the awareness of travel-associated malaria and the need for personal protection against mosquito bites and chemoprophylaxis prior to travel should be stepped up to reduce the incidence of imported malaria among local travellers.[21]

Singapore remains both receptive and vulnerable to the reintroduction of malaria; receptive despite the low *Anopheles* vector population and vulnerable because of the large influx of travellers and foreign workers from the endemic regions. Despite the periodic occurrences of local transmission, malaria has not re-established itself as an endemic disease. Each focus of transmission was completely eliminated through epidemiological surveillance and epidemic vector control operations. In some instances, the reservoir of infection could not be identified despite extensive epidemiological investigations, including mass blood surveys. A few cases with no recent travel history and which occurred singly and sporadically without any epidemiological linkage with other reported cases have been classified as cryptic cases, in accordance to the WHO's definition. Previously malaria-free areas in USA had also reported local transmission, e.g. in New Jersey and New York City.[22,23] In South Korea, despite being declared malaria-free in 1979, there have been large outbreaks with 937,634 indigenous cases reported from 1993 to 2005.[24]

A high degree of vigilance over the disease and vector situation should be maintained. Malaria should be considered as a differential diagnosis in any febrile foreign worker and traveller. Any reported malaria case who does not have a recent travel history should be presumed to have acquired the infection locally and appropriate prevention and control measures promptly taken to pre-empt further transmission. In addition, with the recent identification of simian malaria caused by *P. knowlesi* among 3 national servicemen training in a forested area where long-tail macaques have been sighted, this emerging infection should be considered in a malaria case presenting with daily fever spikes and with malaria parasites morphologically similar to that of *P. malariae*.

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