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Plasmodium falciparum incidence and patency in a high seasonal transmission area of Burkina Faso*

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Abstract

Using a mathematical model *P. falciparum* transition rates were calculated from the parasitological data collected from children of 2 villages of a high and seasonal transmission area in Burkina Faso (West Africa). During the rainy season, patent parasitaemia appeared every 40 to 60 d and was present for 60d approximately. The significance of these values is discussed.

Introduction

Conventional transectional surveys on malaria lead to an evaluation of the parasitological prevalence rate in a population and its variations with respect to age and season. Unfortunately, they do not establish either the incidence rate or the mean duration of the presence of parasites in blood (parasitological patency).

The incidence rate can be estimated from a population of newborn children by observing the onset of parasites, assuming that all newborn children are without any parasites in the circulating blood and that their relationships with *Anopheles* and *Plasmodium* are similar to those of older children or grown-ups.

A cohort study makes it possible to estimate the incidence rate and parasitological patency, using the model of BEKESSY *et al.* (1976). We did this with the juvenile population of 2 West Africa savanna villages where transmission is intense and seasonal.

Materials and methods

Study area

The 2 villages (Tago and Kongodjan) are located 60 km north of Bobo-Dioulasso (Burkina Faso), the former on the tarred road between Bobo and Mopti, the latter 15 km east of this road, in the bush. This is an area of dense savanna, changed by clearing for agricultural purposes. Average rainfall between 1982 and 1984 was 900 mm. The rainy season starts in May and ends in October.

Kongodjan is located in a clay hollow near an artificial permanent pond while Tago is on more porous ground, far from any permanent water.

A parasitological and entomological survey has been conducted in both villages (GAZIN *et al.*, 1985; ROBERT *et al.*, 1985). The results presented here are related to the period from the end of 1982 to early 1985.

Entomological survey

The aggressive anopheline, population was studied by the all night catches on human beings. Two night catches were performed consecutively every 4 weeks between 2000 h and 0600 h in each village. The captured mosquitoes were identified, and *Anopheles gambiae*, *A. funestus* and *A. nili* were dissected the following morning for examination of salivary glands for sporozoites.

Results have been expressed as the number of infected bites per man over a given period. The entomological inoculation rate (h_e), obtained by multiplying the mosquito density and sporozoite index, has been expressed per man per night and per man per year. This entomological survey lasted the whole duration of the study in Kongodjan and during 1983 only in Tago.

Parasitological survey

Children examined were aged 6 months to 15 years. From each, peripheral blood was taken and thin and thick smears made, stained with Giemsa's stain and examined with a standardized procedure. 50 fields of the thick film were examined to detect malaria parasites (sexual and asexual stages), then 100 fields of the thin film were examined to identify species and evaluate the parasite density. Therefore we examined about 100 000 red blood cells. The parasite detection threshold was estimated at 100 parasitized red blood cells per mm^3. Any "negative" sample could then contain from 0 to 99 parasitized cells/mm^3.

Estimation of the daily incidence and recovery rates

Only individuals whose blood was taken in 2 consecutive surveys were included in the study. For each survey they were classified as *P. falciparum* carriers and non-carriers, disregarding the stage. Other *Plasmodium* species have not been taken into account. Transition frequencies from positive to negative and reciprocally were calculated as follows. α, the proportion of individuals which became positive in the second survey, but were negative in the first, is given by

$$\alpha = \frac{N-+}{N-};$$

β, the proportion of individuals which became negative in the second survey, but were positive in the first; is given by

$$\beta = \frac{N+-}{N+}.$$

The incidence rate h can be estimated from the proportions α and β by the following formula:

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$$\hat{h} = \frac{\alpha}{t(\alpha+\beta)} \times \log \frac{1}{1-(\alpha+\beta)}.$$

The recovery rate r is estimated thus:

$$\hat{r} = \frac{\beta}{t(\alpha+\beta)} \times \log \frac{1}{1-(\alpha+\beta)},$$

t being the duration of the interval between 2 surveys, in days. With these formulas, no estimate is possible if $(\alpha+\beta)\geqslant 1$.

For better understanding, $\hat{h}$ and $\hat{r}$ are expressed in the text as percentages.

$\frac{1}{\hat{h}}$ corresponds to the parasitological latency duration, i.e. the duration of initial absence of parasites from the peripheral blood;

$\frac{1}{\hat{r}}$ corresponds to the parasitological patency duration, i.e. the duration of parasitaemia; and

$\frac{\hat{h}}{\hat{h}+\hat{r}}$ corresponds to the equilibrium value of the parasite rate.

Results

Malaria transmission level

The seasonal transmission of malaria was mainly by *A. gambiae* and *A. funestus*, and it varied from one village to the other.

In Kongodjan, transmission occurred from the beginning of June till the end of December. Maximal registered values were 2·4 infected bites per man per night (Table 1). Each inhabitant received an average of 0·63 infected bites every night during the whole transmission period (133 infected bites per man per year).

Table 1—Number of infective bites per man per night in Kongodjan

	1983	1984	1985
Jan.	0	0	0
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
Jun.	0·26	0·43	—
Jul.	0·77	0·25	—
Aug. (beginning)	2·45	0·51	—
Aug. (end)	0·13	0·62	—
Sep.	0	0·27	—
Oct.	0·82	1·9	—
Nov.	0·28	0·40	—
Dec.	0·14	0·26	—

Table 2—Number of subjects of the survey in Kongodjan

		$N{+}{+}$	$N{+}{-}$	$N{-}{-}$	$N{-}{+}$	Duration (days)
1	Jan. 1983 —Mar.	12	6	6	4	60
2	Mar.— May	7	18	15	4	57
3	May— Jul.	26	4	20	24	65
4	Jul.— Sep.	33	15	9	15	71
5	Sep.— Nov.	43	20	14	14	63
6	Nov.— Feb. 1984	13	38	30	1	90
7	Feb.— May	1	11	56	4	69
8	May— Jul.	4	2	36	24	70
9	Jul.— Nov.	25	10	12	27	119
10	Nov.— Mar. 1985	25	34	24	10	110
11	Mar.— May	6	12	28	5	84

See text for explanation of symbols.

Table 3—Values of $\hat{h}$, $\hat{r}$, $\frac{1}{\hat{h}}$, $\frac{1}{\hat{r}}$, $\frac{\hat{h}}{\hat{h}+\hat{r}}$ and observed parasitological index in Kongodjan

	1	2	3	4	5	6	7	8	9	10	11
$\hat{h}$	0·012	0·011	0·014	0·026	0·016	0·001	0·004	0·010	0·023	0·006	0·004
$\frac{1}{\hat{h}}$	83	91	71	38	62	1000	250	100	43	167	250
$\hat{r}$	0·010	0·036	0·003	0·013	0·010	0·016	0·056	0·009	0·009	0·012	0·017
$\frac{1}{\hat{r}}$	100	28	333	77	100	62	18	111	111	83	59
$\frac{\hat{h}}{\hat{h}+\hat{r}}$	0·55	0·23	0·82	0·66	0·62	0·06	0·07	0·53	0·72	0·33	0·19
P.I.	0·56	0·45	0·68	0·65	0·65	0·18	0·11	0·51	0·67	0·44	0·23

$\hat{h}$ = estimated daily incidence rate; $\hat{r}$ = estimated daily recovery rate;
$\frac{1}{\hat{h}}$ = estimated parasitological latency, in days;
$\frac{1}{\hat{r}}$ = estimated parasitological patency, in days; PI = observed parasitological index; numbers 1-11 relate to periods in Table 2.

Table 4—Number of infective bites per man per night in Tago

Apr. 1983	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
0	0	0·125	0·125	1·15	1·0	0·52	0	0

In Tago, the duration of transmission was shorter, from June to October. Maximal registered values were 1·1 infected bites per man per night (Table 4). During the transmission period, each inhabitant received an average of 0·58 infected bites every night (82 infected bites per man per year).

Parasitological results

In both villages, the average parasite rate in the 6-month to 15-year age group was approximately 30% during the dry season and 70% during the rainy season. The most frequent species was *P. falciparum*. *P. malariae* prevalence rate was approximately 5% and *P. ovale* 1%. The latter 2 species were commonly associated with *P. falciparum*. Entomological and parasitological results varied in both villages according to the season.

Daily incidence and recovery rates

In Kongodjan, daily incidence rate was about 1% from January to July 1983; it increased during the rainy season up to 2·6% from July to September, then decreased to 0·4% from November to May. The following year's values were similar.

Daily recovery rate varied in the opposite way: it was 1% from January to March 1983, reached 3·6% from March to May, decreased to 0·3% from May to July, then remained at 1·2% till February 1984. From February to May, it reached 0·55%, then 1% from June 1984 to March 1985 (Tables 2 and 3).

In Tago, daily incidence rate was about 0·7% from December 1982 to June 1983; it reached 2·2% from June to September, then decreased to 1·2% from September to November and was under 0·2% from November to May. In 1984, variations were similar.

Daily recovery rate was about 1% from December to June; it fell to 0·5% from June to September, increased to 0·8% from September to November and to 1·5% from November to May (Tables 5 and 6).

Values of $\hat{h}$ were equivalent in both villages throughout the year. On the contrary, $\hat{r}$ values were higher in Kongodjan than in Tago during the dry season.

Values of $\frac{\hat{h}}{\hat{h}+\hat{r}}$ were close to the observed parasitological rates in both villages, though showing higher fluctuations.
parasitological rates in both villages, though showing higher fluctuations.

Parasitological latency in Kongodjan was 90 d during the dry season, and 40 to 60 d during the transmission season. In the 1984 and 1985 dry seasons, values were extremely high. Parasitological patency lasted for fewer than 30 d in the 1983 and

Table 5—Number of subjects of the survey in Tago

	$N{+}{+}$	$N{+}{-}$	$N{-}{-}$	$N{-}{+}$	Duration (days)
1 Dec. 1982 —Feb.	7	4	6	2	57
2 Feb.— Apr.	7	12	19	4	75
3 Apr.— Jun.	9	8	28	11	69
4 Jun.— Sep.	17	3	10	23	71
5 Sep.— Nov.	19	8	6	5	68
6 Nov.— Feb. 1984	12	19	13	1	76
7 Feb.— May	3	9	28	2	102
8 May— Jul.	2	3	13	17	76
9 Jul.— Nov.	32	5	8	8	117
10 Nov.— Mar. 1985	16	22	10	1	104

See text for explanation of symbols.

Table 6—Values of $\hat{h}$, $\hat{r}$, $\frac{1}{\hat{h}}$, $\frac{1}{\hat{r}}$, $\frac{\hat{h}}{\hat{h}+\hat{r}}$ and observed parasitological index in Tago

	1	2	3	4	5	6	7	8	9	10
$\hat{h}$	0·007	0·005	0·008	0·022	0·012	0·002	0·001	$\alpha+\beta\geq 1$	0·007	0·001
$\frac{1}{\hat{h}}$	143	200	125	45	83	500	1000	—	143	1000
$\hat{r}$	0·010	0·017	0·013	0·005	0·008	0·014	0·015	—	0·002	0·009
$\frac{1}{\hat{r}}$	100	59	77	200	125	71	67	—	500	111
$\frac{\hat{h}}{\hat{h}+\hat{r}}$	0·41	0·23	0·38	0·81	0·60	0·13	0·06	—	0·78	0·10
P.I.	0·43	0·24	0·40	0·72	0·69	0·29	0·14	0·66	0·73	0·41

$\hat{h}$ = estimated daily incidence rate; $\hat{r}$ = estimated daily recovery rate;

$\frac{1}{\hat{h}}$ = estimated parasitological latency, in days;

$\frac{1}{\hat{r}}$ = estimated parasitological patency, in days; PI = observed parasitological index; numbers 1-10 relate to periods in Table 5.

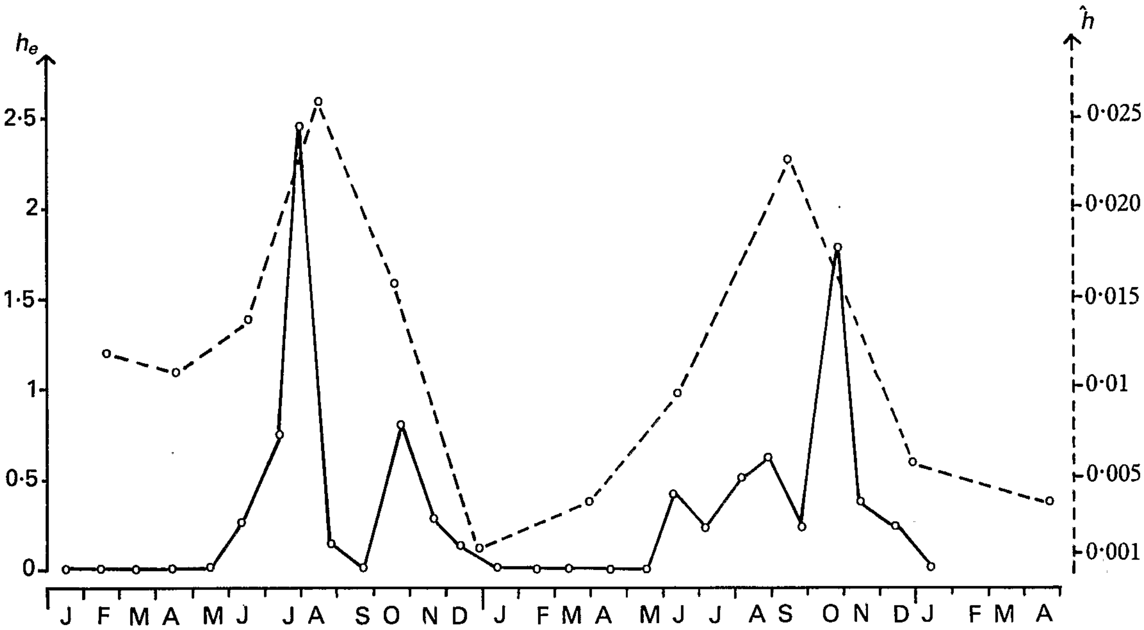

Fig. 1. Comparison between entomological inoculation rate and incidence rate in Kongodjan, 1983-1985; h_e = number of infected bites/man/night; $\hat{h}$ = estimated daily incidence rate.

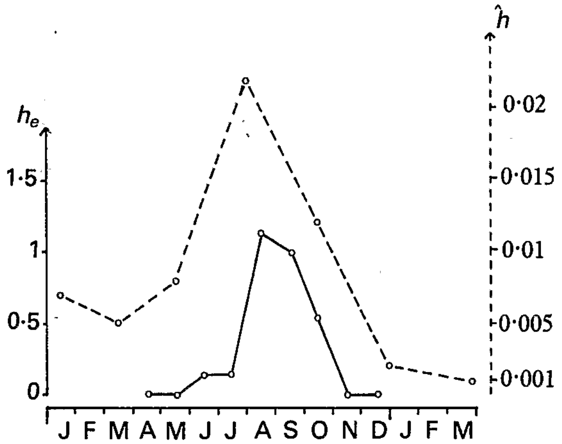

Fig. 2. Comparison between entomological inoculation rate and incidence rate in Tago, 1983-1984; h_e = number of infected bites/man/night; $\hat{h}$ = estimated daily incidence rate.

1984 dry seasons, and for 60 d in 1985. It was about 100 d during the transmission season.

Parasitological latency in Tago lasted about 130 d in the dry season, with extremely high maximum values. In the transmission season, it was about 45 to 90 d. Parasitological patency lasted about 75 d during the dry season and reached extremely high values during the transmission season, more than 200 d.

Discussion

People's attitude towards malaria

Malaria transmission in both villages was so intense that no one could avoid infection (GAZIN *et al.*, 1985b). Nobody took regular chemoprophylaxis. When ill, people used antimalarial drugs (essentially chloroquine), mostly as a low, single dose. This chemotherapy reduced parasite density, but could not be considered a radical cure (BAUDON *et al.*, 1984).

In the absence of transmission, the organism progressively got rid of the parasites. There were only a few low-density carriers remaining by the end of the non-transmission season (April and May).

The recommencement of transmission occurred progressively and accelerated, for both entomological and parasitological reasons. It led to maximum transmission between August and October, along with the highest parasitological rates.

The mathematical model

The model for estimating daily incidence and recovery rates for *P. falciparum* is a simplified approach to the complicated relationship between man and malaria. It measures rates of onset and termination of episodes of patent parasitaemia, and assumes uniformity between persons in the interval.

Our sample size was not sufficient to divide the population into age classes. Nevertheless parasitological rates are relatively homogeneous between 1 and 15 years of age within the same village, mainly during the transmission season (GAZIN *et al.*, 1985). In these conditions separation into age classes does not seem necessary.

Values of $\hat{h}$ and $\hat{r}$ are sometimes very low (<0·5%). A 500 d latency period between November and February would signify only a tendency to lengthen the theoretical latency period, compared with the previous period. Calculated values must not be considered exact values.

Results obtained by other users of the same model

BEKESSY *et al.* (1976) calculated $\hat{h}$ and $\hat{r}$ in Garki (northern Nigeria) in a biotope similar to the surroundings of Bobo-Dioulasso. The values they found showed little seasonal variation, which can be explained by a more accurate detection level of their examination technique (examination of 200 thick film fields).

KRAFSUR & ARMSTRONG (1978) calculated $\hat{h}$ and $\hat{r}$ in Gambela, a small Ethiopian urban community where seasonal transmission is less than 15 infected bites per man per year. Among 0 to 14 year old children, $\hat{h}$ and $\hat{r}$ values were close to our observations.

CARNEVALE (1979), in what is now the People's Republic of the Congo, in a high and almost permanent transmission area, found a short latency period among children of about 50 d and an even shorter patency of about 25 d, with important and suprising seasonal variations.

COOSEMANS (1985) studied, in Burundi, 2 villages located in different biotopes, one in a cottonfield area, the other in a ricefield area. In the latter, the incidence rate was an average of 4 times as much as in the cottonfield area, whereas the recovery rate was longer nearly all year round.

DENG DA *et al.* (1985) observed in China, in a low transmission area, a low daily parasitological inoculation rate of 0·0012, near the daily entomological inoculation rate (0·0019). This situation was very different from those observed in sub-saharan Africa.

Comparison between entomological and calculated values of h

During the high transmission season, average daily inoculation rates were about 30 times higher than incidence rates, calculated from the parasitological data (Figs 1 and 2). These findings emphasize the complexity of the relationship between man and malaria parasites in high transmission areas. In spite of daily infection man shows evidence of a patent parasitaemia only every 40 to 60 d. It is however possible that parasites stay in the blood at a density lower than our detectability threshold.

Immune protection and the use of antimalarial drugs, even at small doses, greatly limit parasite proliferation. As far as we know, all attempts at malaria modelling are inadequate to explain and to measure this part of the relationship between man and malaria parasites. The $\hat{h}$ and $\hat{r}$ calculation implies that malaria is a disease involving accumulation of parasites, when it affects a population with a high level of immunity.

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