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Transmission dynamics of miracidia of *Schistosoma haematobium* in the Volta Lake*

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Schistosoma haematobium *miracidia were detected in sentinel snails placed in 16 human water contact sites in the Volta Lake, each month from March 1973 to November 1977. Results showed that rates of infection were seasonal, and that infected snails were more often found in water contact sites sheltered by emergent plant growth than in exposed open beach sites with no emergent vegetation. Sentinel snail infection rates were correlated with natural snail infection rates and with epidemiological levels of schistosomiasis in village inhabitants. After two years of chemotherapy and mollusciciding, levels of disease and sentinel snail infection rates dropped in two-thirds of the villages. In the remaining villages, however, the sentinel snail infection rates were not correlated with the fall in epidemiological level, because of ecological changes in the water contact sites.*

It is concluded that, unless control measures are continued, the constant changes in the lake shore environment will lead to a rapid re-establishment of previous levels of disease transmission.

The study of the transmission dynamics of schistosomiasis is essential to an understanding of the epidemiology of the infection. Increasing attention is being given to the dynamics of miracidia in the transmission cycle. Schistosome miracidia cannot be studied directly in natural waters, and the only way to monitor changes in miracidial density is to study infected snails. However, the constant fluctuation of natural snail populations precludes their use and the only practical approach is to expose fixed numbers of laboratory-bred (sentinel) snails in natural transmission sites at regular intervals. Such studies on *Schistosoma mansoni* in St Lucia have been reported by Upatham (*1-4*). This report presents the results of studies on the miracidial transmission of *S. haematobium*, which formed part of the WHO/UNDP Schistosomiasis Project on the Volta Lake, and which were intended to assess the effects of various factors, especially chemotherapy and mollusciciding.

MATERIALS AND METHODS

Snail breeding and rearing

Wild *Bulinus rohlfsi*, the intermediate host of *S. haematobium*, were collected from the Volta Lake. Five adult snails were placed in each of sixty 10-litre plastic bowls containing 6 litres of stream or lake water and kept in a shaded, airy room. Maximum water temperature ranged between 27 °C and 31 °C, and the water was changed every 2–3 days. The adult snails were allowed to lay eggs for a period of ten days, after which they were removed and the eggs left to hatch. Baby snails were fed tropical fish food or, in very hot weather, a mixture of fish food and dried lettuce powder. After two weeks of age, snails were fed only dried lettuce. Up to 50 snails could be raised in each plastic bowl.

Sentinel snail cage

The cages were copied from the design used in the Rockefeller Project in St Lucia (*1*), and were made of 2-mm mesh nylon screen, in the shape of an envelope, 10 x 15 cm. The edges of the cages were heat-sealed. A U-shaped piece of PVC tubing was used as an internal support. The cages were covered with a protective welded wire frame to prevent damage and thus improve sentinel snail survival.

Location of cages in the water

In an attempt to determine the most suitable location for sentinel snail cages, an experiment on the dispersal of miracidia was conducted in the field. An area of the lake away from human water contact sites was selected, where the water was 1 m deep. Cages were placed in concentric circles 1–2 m from a central

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point. One-third of the cages were suspended 10 cm below the water surface, one-third 50 cm deep, and the remainder 100 cm deep. Urine containing about 150 000 *S. haematobium* eggs was then poured into the water at the central point. The snails were collected from the lake 24 hours later, kept for 27 days, and crushed to examine for cercariae.

None of the snails kept at the 10 cm and 50 cm depths became infected, but 11 out of 68 (16.2%) placed at the lowest level were found to be positive. This result agrees with Shiff's finding (*5*, *6*) that *S. haematobium* miracidia tend to be more concentrated near the bottom of shallow field water. It is possible that the eggs hatched close to the bottom cages and therefore miracidia were most concentrated there, while local water currents probably reduced the concentration at the higher levels. Hence, it was decided to place all sentinel snail cages near the bottom of the lake near shore during the monthly field surveys.

Determination of infection

It was initially intended to study the relationship between the number of daughter sporocysts and the number of successful miracidial penetrations of the sentinel snails. However, under field conditions, it was impossible to detect clearly the mother and daughter sporocysts. Different rates of maturation of the daughter sporocysts made examination tedious, and the number of abnormal or amorphic forms of daughter sporocysts (*7–9*) made it impossible to differentiate various types of trematode infection from *S. haematobium*. Assessment was therefore based simply on the presence of mature or immature schistosome cercariae upon crushing of the snails 30 days after retrieval from the lake.

Field studies

Two-month-old laboratory-bred *B. rohlfsi* were exposed each month in the main human water contact sites of 16 selected villages in the project area. In each village, 10 cages containing a total of 100 snails were placed in the water and left *in situ* for two days. After retrieval, the exposed snails were kept in the laboratory for 30 days before they were crushed and examined with a dissecting microscope for the presence of schistosome cercariae.

Data collection began in March 1973 in 8 villages and was extended to 16 villages during March and April 1974. Results obtained in this early period up to completion of the first round of selective population chemotherapy (SPC 1) in February 1976 were taken as baseline data. Two further rounds of chemotherapy were completed in 1976 and 1977, and data collected during this period should reflect the results of the campaign. No reliable data were obtained after November 1977, because of a lack of suitable snails.

The level of disease in the human population is expressed as an epidemiological index. This is defined as the product of the disease prevalence rate and the geometric mean of eggs counted in 5 ml samples of positive urine, divided by 100. The pre-intervention epidemiological indices were based on data collected in a survey of all 26 villages in 1974. The post-intervention parasitological surveys were carried out 6–10 months after the start of SPC 1 and 4–9 months after SPC 2.

Monthly sampling of field snails was also conducted in 14 of the 16 WCSs used for sentinel snail exposures. Snails were collected by the palm-mat sampling method in 8 villages and by the modified man-time method, using dip-nets, in 6 villages (*10*). All snails collected were brought back to the field laboratory and examined for both mature and immature cercariae. As in the sentinel snail programme, the pre-intervention baseline data period was from March 1973 to May 1975, when intervention by focal mollusciciding was started in all suitable WCSs.[a]

RESULTS

Seasonal variations

The pre-intervention baseline data for the monthly sentinel snail infection rates and the annual lake water level fluctuation, between March 1973 and February 1976, are shown in Fig. 1. Infection rates were found to be seasonal, with high rates at periods of high water level and low rates at periods of low water level.

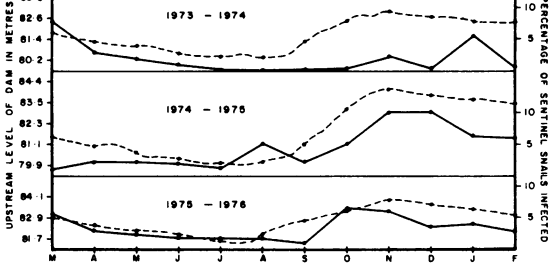

Fig. 1. Water level fluctuations (dashed line) and sentinel snail infection rates in water contact sites (solid line), in the Volta Lake, 1973–76.

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[a] The mollusciciding programme did not affect the sentinel snail programme, since cages were always retrieved before the monthly spraying with niclosamide. Molluscicidal action in a WCS was short-lived and there was no residual effect because the WCSs shifted continually with the rise and fall in the water level.

Table 1. Number of water contact sites found positive in monthly sentinel snail exposures, 1973-76

Type of WCS	March 1973-February 1974		March 1974-February 1975		March 1975-February 1976		Total	
	No. positive/ No. tested	%	No. positive/ No. tested	%	No. positive/ No. tested	%	No. positive/ No. tested	%
Open beach	11/42	26.2	35/65	53.8	24/75	32.0	70/182	38.5
Pocket	14/31	45.2	45/60	75.0	33/55	60.0	92/146	63.0
Channel	7/23	30.4	18/34	52.9	18/35	51.4	43/ 92	46.7

Ecological types of WCS

Water contact sites in the lake were subject to change because of the annual cycle of water level fluctuation (*10*). Three main types of WCS were observed: open beaches, pockets, and channels. Open beach sites were most common at low water level and were found on wide exposed stretches of shoreline where little or no emergent vegetation grew in the water. Channel-shaped sites, mainly cut through dense *Polygonum senagalense* from the shore to the open water, started to appear in late August when the water level began to rise, and predominated from high water level to the early drawdown phase. Pocket-shaped WCSs were also numerous at high water level and early to mid-drawdown, i.e., from September to March. Details of the formation of such WCSs are described elsewhere (*10*).

If any sentinel snails became positive after exposure in a WCS, that site was considered positive for miracidial transmission. Table 1 shows the number of times each WCS was positive between 1973 and 1976, grouped according to the type of site. Over the three-year period, the number of sentinel snail infections in pocket-shaped WCSs was significantly higher than that in channel-shaped sites ($\chi^2 = 6.09$, $P<0.05$). There was no significant difference in infection rates between channel-shaped and open beach WCSs ($\chi^2 = 1.73$, $0.1<P<0.2$).

Natural snail populations

In the main WCSs used for both sentinel snail exposures and ecological snail sampling, the highest numbers of field *B. rohlfsi* and of infected specimens were found in January, February, and March. Few snails were found in September and October because of the rapidly rising water level. At lowest water levels (April-July), *B. rohlfsi* were found almost exclusively in WCSs with moderate to heavy growths of *Ceratophyllum.*

From Fig. 1, it can be seen that peak sentinel snail infection rates occurred in March 1973, January, November, and December 1974, and October and November 1975. Except for the latter two months, these peak transmission periods coincided with the peak periods of field snail infections.

Comparative results of sentinel snail and field snail infection rates in the WCSs of 14 villages from March 1973 to May 1975 are presented in Table 2. At Pawmpawmnya No. 1, on the steeper eastern shore of the lake, 2157 sentinel snails were examined and only 12 were positive, an infection rate of 0.56%. During 27 consecutive months of field snail sampling at the same site, only one snail was found (in December 1974 when the site was pocket-shaped in emergent vegetation for one month), and it was positive for cercariae. The epidemiological index of Pawmpawmnya No. 1 has always been low because the WCSs in the village have almost always been open beaches devoid of weed growth. If this atypical village is omitted from the analysis, infection rates of sentinel and field snails in the remaining 13 villages were significantly correlated ($r = 0.52$, $P<0.05$).

Epidemiological levels of schistosomiasis

The epidemiological indices of disease and the overall sentinel snail infection rates in all 16 villages before the completion of SPC1 are shown in Table 3. The snail infection rates were significantly correlated with the epidemiological indices of schistosomiasis in the villages ($r = 0.79$, $P<0.01$).

Effects of intervention

Table 4 shows the sentinel snail infection rates before completion of SPC 1 and the post-intervention data collected after completion of SPC 1 and SPC 2. Of 16 villages studied, a significant reduction in miracidial transmission occurred in 9 villages following SPC 1 and in 11 villages after SPC 2. In the villages of Kasa and Asakeso, miracidial transmission rose following drug treatment because the villagers changed from their original WCS to a new, smaller one. In Pawmpawmnya 1, positive results were

Table 2. Sentinel and field snail infection rates in the water-contact sites of 14 villages, March 1973–May 1975

Village	Sentinel snails		Field snails	
	No. positive/No. tested	%	No. positive/No. tested	%
Pawmpawmnya No. 1[a]	12/2157	0.56	1/1	100.0
Fatem	97/2303	4.21	11/145	7.59
Kasa	95/2272	4.18	8/140	5.71
Poakwe Pawmpawmnya	32/2327	1.38	14/783	1.79
Dawa Kofi	55/1308	4.2	12/97	12.37
Akokoma	31/1107	2.8	1/71	1.41
Kwabia	64/2177	2.94	1/31	3.23
Kuma Kuma	91/2201	4.13	19/106	17.92
Asakeso	45/2146	2.1	16/457	3.5
Akotui West	113/2295	4.92	171/1518	11.26
Tamayeso	87/1068	8.15	4/49	8.16
Nyafutu	29/965	3.0	0/32	0
Dukuase	67/974	6.88	32/367	8.72
Odortom II	87/1165	7.47	35/330	10.61
Total	905/24 465	3.70	325/4127	7.87

[a] If results from Pawmpawmnya No. 1 are omitted, $r = 0.52$, $P<0.05$.

Table 3. Pre-intervention epidemiological index and sentinel snail infection rates in 16 villages, 1974–75

Village	Epidemiological index[a]	Snail infection rate (%)
Odortom II	72.26	7.88
Tamayeso	67.90	6.56
Akotui East	54.85	3.44
Dukuase	54.74	8.11
Akotui West	49.65	4.54
Nyafutu	47.13	2.58
Akrusu	42.26	7.82
Dawa Kofi	37.98	3.77
Fatem	31.91	3.39
Kasa	27.64	3.35
Poakwe Pawmpawmnya	25.00	1.14
Kwabia	23.94	2.52
Kuma Kuma	23.32	3.58
Asakeso	22.56	2.04
Akokoma	21.52	1.91
Pawmpawmnya No. 1	5.79	0.45

[a] Epidemiological index = disease prevalence x geometric mean egg count per 5 ml of urine/100.

obtained in only two of the 33 pre-intervention exposures, providing further evidence that transmission was low and sporadic. At Akotui East, the WCS used for the sentinel snail exposures was frequently pocket-shaped before the start of chemotherapy, but later became an open beach habitat because of the continuing drop in lake level during 1976 and 1977. No infected snails were found in this WCS after SPC 1, even though the epidemiological index in the village remained fairly high. At Odortom II, a significant reduction in miracidial transmission was obtained after SPC 1, but transmission increased after SPC 2. This occurred after the falling water level enabled offshore *Ceratophyllum* to invade the WCS and to maintain a submerged, semi-barrier around it, keeping the water calm and helping to concentrate miracidia closer to the sentinel snails.

DISCUSSION

The changes in the lake water level greatly affected the miracidial detection programme. Each year, sentinel snail infection rates were highest in the season of early lake drawdown and lowest at low water. At high water level, WCSs were smaller because of the

Table 4. Effects of the chemotherapy programme on sentinel snail infection rates in 16 villages

Village	Pre-intervention		Post-intervention			
			1976[a]		1977[b]	
	No. positive/ No. tested	%	No. positive/ No. tested	%	No. positive/ No. tested	%
Pawmpawmnya No. 1	12/2697	0.45	0/934	0	0/569	0
Fatem	97/2858	3.39	3/919	0.33[c]	5/812	0.62[c]
Kasa	95/2833	3.35	68/938	7.25[c]	101/812	12.44[c]
Poakwe Pawmpawmnya	33/2898	1.14	9/943	0.95	1/824	0.12[c]
Dawa Kofi	69/1831	3.77	24/854	2.81	6/632	0.95[c]
Akokoma	31/1619	1.91	10/885	1.13	4/676	0.59[c]
Kwabia	69/2735	2.52	2/883	0.23[c]	1/558	0.18[c]
Kuma Kuma	103/2878	3.58	4/868	0.46[c]	3/826	0.36[c]
Akrusu	82/1049	7.82	33/751	4.39[c]	20/716	2.79[c]
Asakeso	57/2791	2.04	28/785	3.57[c]	25/705	3.55[c]
Akotui West	134/2949	4.54	20/977	2.05[c]	5/585	0.85[c]
Akotui East	41/1193	3.44	0/691	0[c]	0/577	0[c]
Tamayeso	118/1799	6.56	17/791	2.15[c]	9/662	1.36[c]
Nyafutu	43/1664	2.58	10/658	1.52	13/660	1.97
Dukuase	139/1714	8.11	28/734	3.81[c]	21/672	3.13[c]
Odortom II	163/2069	7.88	6/654	0.92[c]	44/628	7.01

[a] After one round of chemotherapy.

[b] After two rounds of chemotherapy.

[c] Significant difference pre- and post-intervention, $P<0.05$.

wide zone of marginal emergent vegetation, and the majority of the sites were pocket-shaped. The side vegetation and the shore itself created barriers which concentrated the miracidia inside the WCS while keeping the water calm. Such well-defined sites made it very easy to pinpoint the centre of human water-contact activity. In this condition, both miracidial and cercarial transmission were focal and consistent (*11*). Channel-shaped WCSs were also common at high water levels, but because human activity was confined to narrow spaces near the shore, the sentinel snail cages in the water were often disturbed. The increased pollution near the shore also increased sentinel snail mortality and reduced miracidial infection rates. Almost all WCSs were of the open beach type at low water level each year. With no emergent vegetation in the water to confine human activity, water contact was more diffuse and miracidial density was considerably reduced. Sentinel snail infection rates in these WCSs were always very low except when moderate to heavy growths of *Ceratophyllum* were present.

While it is often difficult to pinpoint human water-contact sites in other schistosome habitats such as irrigation canals, ponds, and swamps, the WCSs in the Volta Lake were usually very distinct and consistent. Intensity of water contact was high, not only because the villagers were mainly fisherfolk, but also because the lake water was of good quality and therefore attractive as a water source. Also, during the hot season, children often used the open beach WCSs for swimming and playing. With such intensive water contact in all villages, a correlation between sentinel snail infection rates and the epidemiological index of the disease in the villages would be expected.

In the St Lucia schistosomiasis control project miracidial detection using sentinel snail exposure was used to help evaluate the efficacy of chemotherapy (*12, 13*), and no infected snails were found after chemotherapy had been started. In the present project, infection rates of sentinel and field snails were found to be proportional to the epidemiological indices of schistosomiasis in the villages in the pre-intervention period. However, the results after intervention were quite different. Sentinel snails were uninfected in only 2 of 16 villages studied. In 9 of the remaining 14 villages, the reduction in sentinel snail infection rates was proportional to the reduction in epidemiological levels of the disease. In the remaining 5 villages, however, there was no such relationship because of the ecological conditions of the WCSs changed thus favouring transmission.

Control of schistosomiasis in this area is difficult because of: (1) the poor cure rate of metrifonate in a high endemic area, (2) the high level of migration of the population looking for more productive fishing and farming grounds, (3) the large number of untreated people living in hinterland villages, 1–5 km from the lake, and (4) the large proportion of untreated people living in the villages undergoing intervention. Even where the project reduced epidemiological indices and sentinel snail infection rates by 90%, the residual disease could lead to a build-up of cercarial transmission within 2–3 months if snails were present during the main transmission season.

From this study, it can be concluded that chemotherapy, molluscicfiding, and limited well-water supply are not sufficient to stop transmission of *S. haematobium*, although they achieved excellent results in the short-term control of transmission and infection. Permanent control would require the virtual eradication of infection from the project area, the nearby hinterland villages, and a wide zone along the lake on each side of the project area.

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RÉSUMÉ

DYNAMIQUE DE LA TRANSMISSION DES MIRACIDIES DE *SCHISTOSOMA HAEMATOBIUM* DANS LE LAC VOLTA

Pendant cinq ans, on a effectué des études sur la dynamique de la transmission des miracidies de *Schistosoma haematobium* tous les mois dans seize villages lacustres en plaçant des mollusques sentinelles dans des lieux de contact homme-eau.

On s'est aperçu que les taux d'infection des mollusques sentinelles avaient un caractère saisonnier, qu'ils étaient élevés lorsque le niveau de l'eau était haut et peu élevés lorsque le niveau de l'eau était bas. On a découvert que les mollusques étaient plus souvent infectés dans les petites poches d'eau que dans les plages ou canaux largement ouverts. Les maximums dans les taux d'infection des mollusques sentinelles étaient comparables à ceux des mollusques vivant à l'état naturel et correspondaient aux niveaux épidémiologiques de la schistosomiase parmi les habitants locaux.

Après deux ans d'intervention par chimiothérapie et l'emploi de molluscides, les taux d'infection des mollusques sentinelles n'avaient diminué que dans deux tiers des villages. Dans les autres, le changement dans le taux d'infection des mollusques sentinelles ne correspondant pas à la baisse des niveaux épidémiologiques, en raison de modifications écologiques dans les lieux de contact avec l'eau. Certaines modifications de ces lieux de contact entraîneront rapidement une reprise du taux de transmission de la maladie même après une baisse de 90% des niveaux épidémiologiques.

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