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Schistosoma and Schistosomiasis

SCHISTOMIASIS is one of the major parasitic diseases of man. It affects many countries and, especially in Africa, it has increased in importance following the development of manmade lakes and irrigation schemes.

Description of Pathogen and Disease

The literature on schistosomiasis is truly voluminous, and only a brief summary of the salient features can be given here. A series of major abstracted bibliographies, most recently Hoffman and Warren (1978), provides an invaluable guide to the literature on schistosomiasis for those wishing to study particular aspects in greater detail.

Identification

Schistosomiasis, known in the older literature and in common usage as bilharziasis, comprises infections of the venous system by several species of the trematode genus *Schistosoma*. One species, *S. haematobium*, inhabits the veins around the bladder (urinary schistosomiasis), whereas the others predominantly involve the portal venous system that transports blood from the intestines to the liver (intestinal schistosomiasis). The most important species of intestinal schistosome are *S. mansoni* and *S. japonicum*; *S. intercalatum* is similar to these but has a localized distribution in West Africa.

The range of disease produced in infected individuals is very great. Infection is through the skin and may be accompanied by itching and skin inflammation. Early development in the lungs may give rise to marked fever and respiratory symptoms. The adult worms in the veins give rise to few disorders; the problems arise from the eggs, of which each female worm lays hundreds, or thousands in the case of *S. japonicum*, daily. A proportion of these escape into the bowel or bladder and are responsible for transmission to other persons as well as for damaging the tissues through which they pass. The majority of eggs are retained in the body, either in the bowel and bladder wall, or are carried to the liver, where many become stuck in the blood vessels, or to the lungs and even the brain or spinal cord on occasion. An impacted egg induces a chronic inflammatory response around it; the size of reaction depends in part on acquired immune responses. Gradually the egg becomes calcified (especially in the bladder wall) or destroyed.

Escaping eggs cause tissue damage with loss of blood and protein into the urine (where it is obvious) or feces. The heavier the infection, with more eggs being passed, the greater the blood loss, and up to thousands of worm pairs have been found at autopsy. With an inflamed bladder wall, caused by the passage of *S. haematobium* eggs, urine is passed frequently and painfully. Growths in the bladder lining may occur, and they or the schistosome eggs act as nuclei for the formation of urinary stones. In a few people infected with *S. haematobium*, bladder wall damage leads on to cancer and death. Reactions to retained eggs may block the escape of urine from the kidneys to the bladder in up to 20 percent of infected children, and the resulting back pressure may damage or even destroy the kidney. Where this is bilateral, renal failure and death follow, but the ureteric lesions of a fair proportion of patients are reversible with chemotherapy.

The intestinal schistosomiases (*S. mansoni* and *S. japonicum*) cause occult bleeding into the bowel, papillomata of the bowel wall, and, in heavy infections, bouts of dysentery with passage of blood. The brunt of damage falls on the liver, and although all cases have scattered reactions to impacted eggs, in a proportion (usually small but reaching 23 percent in one community) there is a proliferation of fibrous tissue to produce a fibrous liver. A fibrous liver may function badly, leading to hepatic coma, but more usually the main effect is a back pressure on the blood supply, with great enlargement of the spleen and a series of bypasses developing that return blood to the heart other than through the liver. Such blood vessels above the stomach may burst and give rise to profuse bleeding from the mouth, which may be lethal. Yet other eggs may reach and damage the lungs or the nervous system, but a swollen abdomen with ascites from the liver damage is more frequent. These life-threatening complications occur mostly in the heavily infected, but even light infections give rise to lassitude in many patients. Others may have few or no symptoms, although even some of these, if heavily infected, have decreased ability to do physical work (Awad El Karim and others 1981) and impaired growth in childhood.

Diagnosis is by the identification of *Schistosoma* eggs in the feces (for *S. mansoni* and *S. japonicum* infections) or in the urine (for *S. haematobium* infections). Serological techniques for diagnosis are also available and are useful in mass surveillance in support of control programs (see, for instance, McLaren and others 1979). Treatment of infections is by drug therapy, and great advances in drug development have been made in recent years. Hycanthone or oxamniquine are often used for *S. mansoni* infections; hycanthone, niridazole, or metrifonate for *S. haematobium*; and niridazole for *S. japonicum*. Praziquantel, a newer drug still undergoing field trials, is effective against all three schistosome species.

Occurrence

Human schistosomiasis is found in many parts of the tropics, with some 200 million cases in all. Unlike most other infections, it has been steadily spreading and increasing in intensity over much of its range for some decades, as a result of water impoundments for power and agriculture and the development of irrigated farming. Urinary schistosomiasis (due to *S. haematobium*) occurs throughout the inhabited parts of Africa and is particularly common in the Nile valley. It extends into irrigated and other parts of the Middle East, with small foci in South Asia and Europe (figure 32-1). *S. mansoni* is widespread in Africa and in Brazil and other countries of northeast South America, with a patchy distribution in the Caribbean (figure 32-2). Of the other intestinal schistosomiases, *S. intercalatum* has a restricted distribution in central West Africa, whereas *S. japonicum* occurs in the Philippines, Sulawesi, China, and other parts of Southeast Asia and was formerly important in Japan (figure 32-1). A closely related form is found along the Mekong River.

Within endemic areas the prevalence in schoolchildren of urinary schistosomiasis may often exceed 80 percent, and this level is reached at a later age for *S. mansoni*. Worm loads in a few people will be in the thousands, although the majority will be less heavily infected. The proportion going on to progressive disease will vary with intensity of infection. It may be locally up to 25 percent, but a lower proportion is usual, and of these only some will die of liver or urinary tract disease, most of them during early to middle adult life.

Infectious agents

The schistosomes are digenetic trematodes in which the sexes are separate and differ in size and shape. The broader males are around 10 millimeters in length, and the slender female normally lies enclosed by the folded body of the male (figure 32-3). The several species that infect man are most readily distinguished by the shape of their eggs: those of *S. haematobium* and *S. intercalatum* have a terminal spine, whereas *S. mansoni* eggs have a lateral spine, and *S. japonicum* eggs are rounded with a small knob. Several more or less closely related blood flukes infect domestic animals and birds. The bird schistosomes can give rise to dermatitis in bathers in temperate climates.

Reservoirs

Man is the effective reservoir of *S. haematobium* and *S. mansoni*. Though wild animals may become infected with *S. mansoni* and one small epidemic was traced to infected baboons, they may for practical purposes be disregarded. *S. japonicum* is a zoonosis, however, and in fact the Taiwan strain is noninfective to man and entirely transmitted between animals. Elsewhere, a variety of domestic animals — dogs, cattle, water buffaloes, and rats — act as reservoirs of infection, although man is still usually responsible for the majority of transmission, it is likely that it would continue, albeit at a lower level, in his absence.

Transmission

Each paired female worm of *S. mansoni* and *S. haematobium* lays some hundreds of eggs daily, but *S. japonicum* lays thousands. The eggs are large, some 140 micrometers in length, and elongated. The proportion that escape, which may be as low as 20 percent, pass through the tissues into the urine (*S. haematobium*) or feces (other species). Although they take several days to

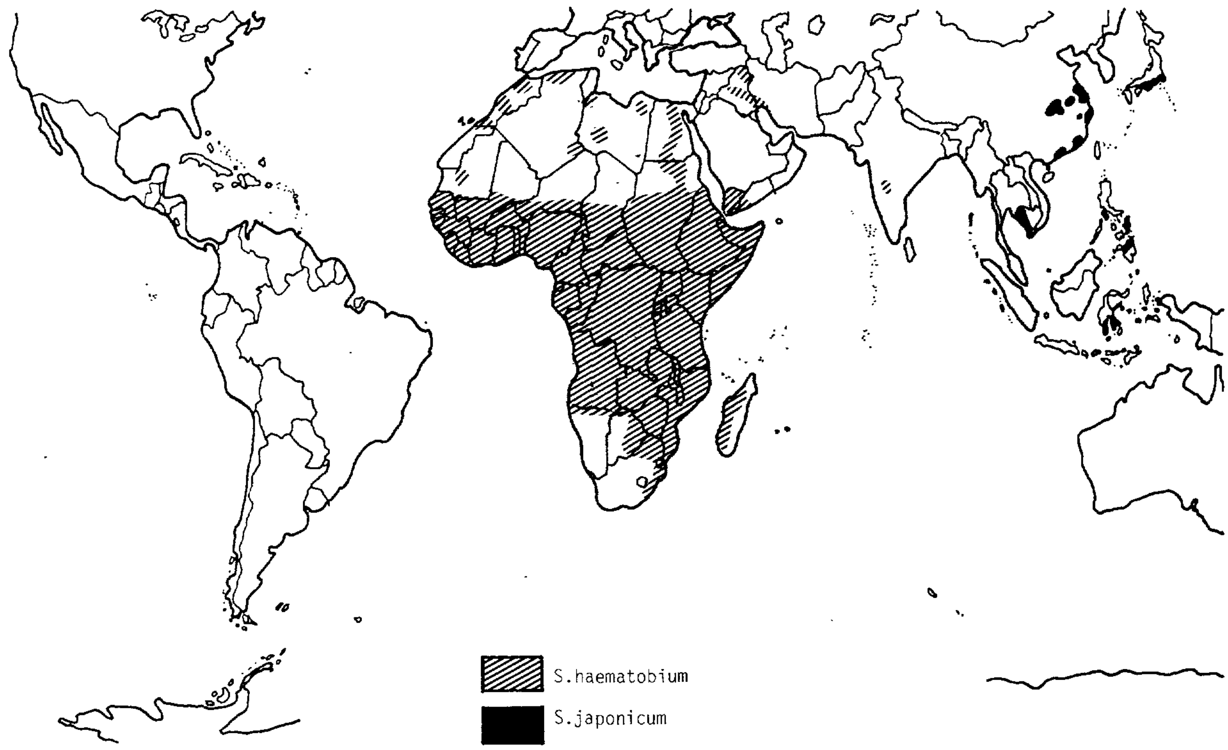

Figure 32-1. *Known geographical distribution of* Schistosoma haematobium *and* S. japonicum. The infections may occur in areas as yet unrecorded. *S. haematobium* transmission is most unlikely at altitudes above 1,500 meters

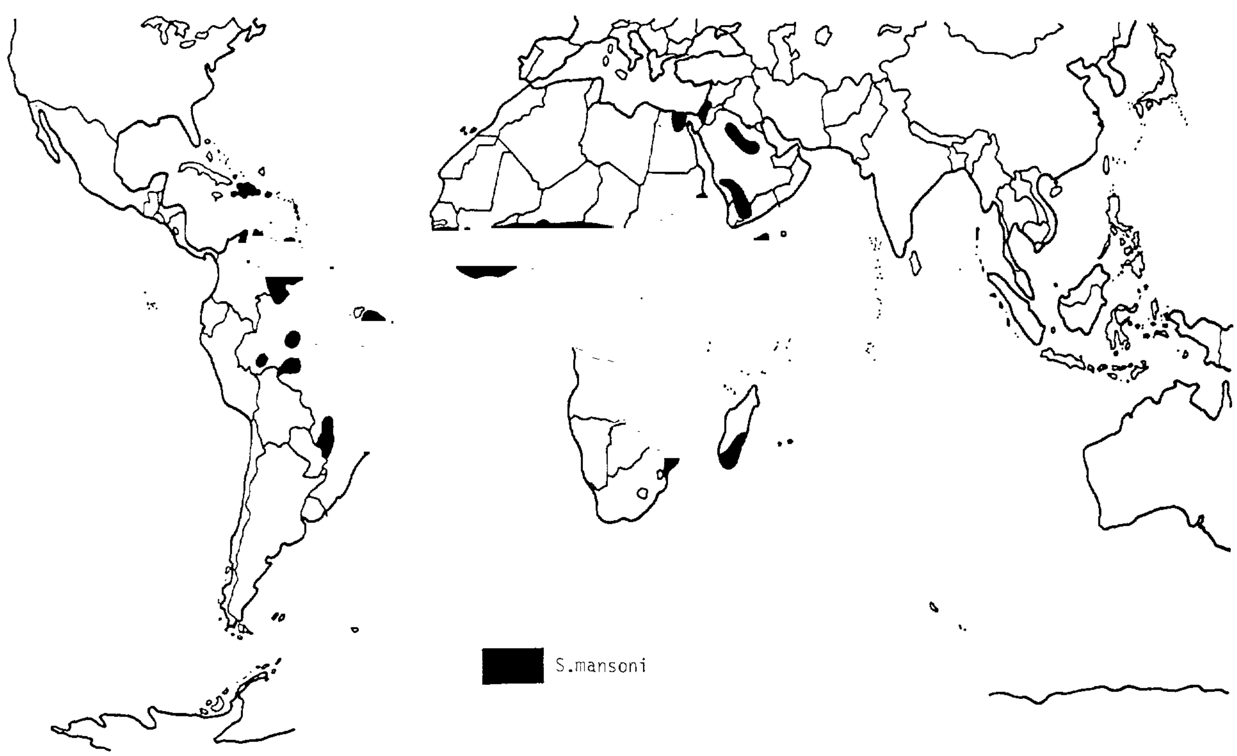

Figure 32-2. *Known geographical distribution of* S. manosni. The infection may occur in areas as yet unrecorded. *S. mansoni* transmission is most unlikely at altitudes above 2,000 meters

Figure 32-3. *A male and female* S. mansoni *under scanning electronmicroscopy*. The slender female (10–20 millimeters long and 0.16 millimeters wide) lies in a groove in the body of the sturdier male (6–12 millimeters long and 1.1 millimeters wide) and can be seen protruding at one end. Scale bar = 1 millimeter. (Photo: M. M. Wong, Primate Research Center, University of California, Davis, California, USA)

develop after being laid by the female, by the time they pass out of the body with the excreta they are mature and ready to hatch. After the worms have died or been killed by therapy, a few dead and calcified eggs may continue to be excreted over months or years, but these are not hatchable.

The eggs hatch when osmotic pressure of the surrounding medium falls, as when they reach water, and light and warmth speed hatching. The egg shell splits, and a motile ciliated larva called a miracidium emerges and scans the aquatic snail environment for up to 6 hours. On encountering a suitable species of aquatic snail, the larva penetrates it and undergoes a series of developmental stages. Between 1 month and 3 months later, depending on the temperature and on the species of snail, further aquatic larvae called cercariae begin to emerge from the snail. The pattern varies from less than a dozen each day for many months for *S. japonicum* in *Oncomelania quadrasi* to nearly a thousand daily from *S. mansoni* in *Biomphalaria glabrata*, though in the latter case the snail may only survive two weeks of shedding cercariae. These live up to 48 hours in the water, swimming to the surface and then slowly sinking during rest periods, but on encountering human skin they rapidly penetrate it and, after migrating to the lungs where they develop for some days, they move to the portal venous system of the liver to mature and pair before migrating to the intestinal and vesical blood vessels.

The snail hosts vary by region, and the schistosomes are very species specific. The principal genera of snails that act as host for the main species of schistosomes are:

Bulinus	for *S. haematobium*
Biomphalaria	for *S. mansoni*
Oncomelania and *Tricula*	for *S. japonicum*

The hosts of *S. japonicum* are amphibious and leave the water for muddy canal-banks from time to time. The snail hosts of other schistosomes are truly aquatic, although many, even if infected, can survive a dry season by burrowing into the drying mud of a seasonal pond. Still or gently flowing water favors the snails, as does a high calcium content of water, neutral or alkaline pH, and aquatic vegetation. Where scattered families use separate ponds for water supplies the infection can be highly focal, but cercariae may be carried many meters in flowing water to infect downstream settlements.

Although people may become infected through the mucosa of the mouth when drinking water, the bulk of infections are acquired through water contact with the skin.

Prepatent and incubation periods

The shortest times recorded between cercarial penetration and the appearance of *S. mansoni* eggs in the excreta are just over a month, but 2 months is more usual, and a longer period is normal for the other schistosome species. An incubation period cannot be stated because symptoms may develop gradually, or not at all, depending on the number of schistosome worms infecting and the immune status of the host.

Period of communicability

Once mature worm pairs are established, they may persist and continue laying eggs for a long time, and worm survival for 30 years is documented. However, the majority of worms die sooner, and a half-life of 3 to 6 years is probable, though evidence of even shorter survival is appearing (for instance, Goddard and Jordan 1980). In endemic areas, the relative importances of prolonged worm survival and superinfection are not yet well defined. The eggs, once excreted, may persist for weeks or months, as discussed below, but hatch promptly in water and have only a few hours of life thereafter unless a snail is found.

Resistance

Most, if not all, people are susceptible to schistosomiasis, although some races may be more susceptible to the severer forms than others. Acquired resistance due to natural exposure to infection is well documented in several animal species and is clearly indicated to occur in human *S. haematobium* and *S. japonicum* infections. The evidence in *S. mansoni* is equivocal. Acquired immunity is certainly incomplete, and its importance in the natural history of the infections in communities is not well defined. Peak infection loads are usually seen around the age of 10 years in *S. haematobium* and a little later in *S. japonicum*; egg output declines thereafter even where water contact persists.

Epidemiology

The epidemiology of schistosomiasis is a complex and much studied subject, and space does not permit a full discussion here. In a given locality, schistosome dynamics depend upon both the macroecological effects of topography, hydrology, water quality, settlement patterns, agriculture, sanitation, human behavior, snail behavior, and the microecological factors of host-parasite relationships in man and in the snail. The total system is complex, and many gaps in scientific understanding remain, particularly on the role of immunity in natural infections. Attempts to construct mathematical models of transmission, and thus to predict the impact of alternate control strategies, have been mathematically sophisticated but of limited usefulness.

For successful transmission, man must live near to bodies of surface water that have the characteristics (temperature, chemistry, pH, plant life, velocity) necessary to support the appropriate species of snail. For transmission from man to snail to take place, fresh human excreta (urine for *S. haematobium* and feces for other species) must reach these bodies of water where the snail colonies are living. This may happen owing to promiscuous defecation, urination while near or in water, or to the discharge of untreated sewage into water. Finally for transmission from snail to man to take place, there must be a pattern of behavior in the community that causes people to enter regularly those surface waters that harbor the snails and have been polluted by the excreta.

In most communities where schistosomiasis is endemic, prevalence and intensity of infection are highest in the 5–20 age group. This age group is likely to be heavily exposed during play or bathing and possibly also when performing household tasks such as collecting water, tending water buffalo, fishing, or helping a parent in the fields. Adults are exposed to infection while working in irrigated fields, fishing, collecting water, washing clothes, bathing, or any other activity involving water contact.

Different patterns of work may cause differences in schistosomiasis prevalence. Thus, in a village in the Nile Delta (Egypt) women who consistently worked in the fields had a schistosomiasis prevalence similar to men, whereas women who worked exclusively around the home had an appreciably lower rate of infection (Abdel-Wahab and others 1980). Another study in Egypt (Farooq and others 1966) showed that, for males, there was an increased prevalence of *S. mansoni* among fishermen, water carriers, and washermen and an increase in *S. haematobium* infection among boatmen.

The transmission of schistosomiasis can be highly localized both in time and space. Regular seasonal variations can be due to temperature if there is a winter period when snail populations decrease and it is too cold for schistosomes to develop outside their human hosts. Seasonality of transmission can also be due to rainfall and surface water hydrology. High rainfall may wash out snail habitats or swell rivers to a point where water contact is reduced and cercarial concentrations are greatly diluted. More usually, dry periods eliminate ponds and streams completely. It is common in Africa for *S. haematobium* transmission to take place in ponds and waterholes in the wetter seasons, reaching a peak as water bodies shrink and man-water contact becomes more focal in the early dry season, but ceasing later when the ponds dry up and the snails estivate in the mud and await the next rains.

Focal transmission occurs if it is associated not with surface water bodies in general but with certain specific streams or ponds that are polluted by excreta, that support the correct snail species, and that are visited by people for play or work. Thus, as mentioned above, *S. haematobium* transmission may largely take place at one or two sites in or near a village. The correct identification of these sites is essential to the design of control programs.

Two aspects of human behavior are integrally linked with the epidemiology of schistosomiasis: water-contact behavior and excretion behavior. Water-contact behavior has been increasingly studied over the past decade, and these studies are a rare and encouraging example of the value of collaboration between sociologists and epidemiologists.

A water-contact study, in an area of northern Nigeria heavily infected with *S. haematobium*, showed that most contact with water at a dam site took place during fishing, bathing, swimming, and playing (Tayo, Pugh and Bradley 1980). The great majority (94 percent) of all water contacts observed involved males, because females were relatively secluded in this Muslim society. Schistosomiasis prevalences were much higher among males than females in the area. Peak water-contact activity occurred in the afternoon: the time of peak urinary egg output and peak cercarial shedding by infected snails.

Water-contact studies on the shore of Lake Volta (Ghana), another *S. haematobium* area, showed that women were most exposed during domestic tasks such as water fetching and clothes washing and that men were most exposed during swimming, bathing, and entering canoes (Dalton and Pole 1978). Overall, males had more water contact and higher intensities of schistosomiasis infection than females. It is pointed out that piped water supplies and clothes washing facilities in the villages might reduce water contact for females, but would not affect the recreational activities of males or the time they spend around canoes in the shallow water at the lake edge.

Excretion behavior studies are more difficult to carry out than water-contact studies, and there is, as yet, little information on this important aspect of schistosomiasis epidemiology. Studies in the Gezira irrigation scheme in the Sudan by Cheesmond and Fenwick (1981) found that 46 percent of all observed acts of excretion took place before 9.00 AM. Men and women squatted in the open to urinate, although women did not urinate in sight of men. Nearly all observed urination was onto soil, not into water, although children may have urinated unseen while immersed in water. Privacy was the prime determinant of defecation site. 93 percent of defecations took place in the fields in cotton, sorghum, or among trees. Only 31 percent of people washed themselves after excretion and only 7 percent washed their anal region directly into a water body. This study, unlike some others, found that privacy was more important than closeness to water in determining defecation sites and that most observed excretion could not lead to the entry of schistosome eggs from urine or feces into canals or other water bodies.

A study of excretion behavior was carried out in the Nile Delta (Egypt; Farooq and Mallah 1966). Children under 10 years played frequently in water and often urinated while doing so. Both sexes and most ages usually urinated and defecated within 2 meters of water. Boys commonly urinated directly into water. Adult males performed ablution after defecation by squatting close to the water's edge and splashing water and washing with the left hand. Adult females who defecated in the open did so early in the morning or after sunset and did not perform ablution. Although females had more frequent water contact than males, males were observed to contaminate water 5 times more frequently than females, and those girls polluting were mostly under the age of frequent schistosomal infection.

The contamination of surface waters by excreta, and the subsequent infection of snails, occur not only as a result of promiscuous defecation but also because of the discharge of inadequately treated sewage. In Minas Gerais (Brazil) the effluent from a septic tank was entering a stream, and 65 percent of *Biomphalaria glabrata* less than 10 meters from the sewage outfall, 15 percent of those snails between 90 and 100 meters from the outfall, and no snails 200 meters away were infected (Paulini 1964). In addition, snail density was much greater near the outfall because some snail species have a preference for polluted waters (see also Watson 1958). A similar situation in South Africa is reported by Bayer (1954).

Although schistosomiasis is primarily a rural disease, urban communities are also infected. Transmission may take place in urban streams, borrow pits, or ponds, or it may be due to urban people leaving town for recreational or agricultural purposes and becoming infected in the countryside. A survey of residents in San Juan (Puerto Rico) showed that swimming and fishing were the main reasons for water contact and that these activities took place in streams throughout the island. Most water contact involved the 5–19 age group but was not associated with socioeconomic status (Lipes and Hiatt 1977). In a working class suburb of São Paulo (Brazil), where thirty locally acquired infections of children with *S. mansoni* and three infected *Biomphalaria tenagophila* were detected, the sites of transmission were two borrow pits used as communal bathing pools, chiefly by children (Rodriques and Ferreira 1966).

Schistosomiasis is closely related to surface-water hydrology and irrigated agriculture and is therefore sensitive to the development of manmade lakes and irrigation schemes. The typical experience has been that major irrigation and lake development projects in areas of endemic schistosomiasis have increased the prevalence and intensity of this infection among the local population. There are well documented cases of this from Egypt, Ghana, Iran, Nigeria, Sudan, Tanzania, Zambia, Zimbabwe, and elsewhere (Rosenfield and Bower 1979). The development of the lakes and the irrigation and drainage canals increases the number of habitats for snails; the development of irrigated agriculture and fishing increase the frequency and duration of water contact; the increased availability of surface water for recreation also increases water contact; population densities rise to take advantage of the new agroeconomic opportunities; and the fecal contamination of the surface water is assured by the general poverty of the local communities and the lack of concurrent sanitation programs. All these factors contribute to rising transmission rates leading to rising infection rates and, ultimately, to more frank disease.

In some areas, the ecological changes caused by lake and irrigation development may not only increase schistosomiasis transmission but may also affect the type of schistosomiasis that is dominant. Thus, in some villages in the Nile Delta (Egypt) the major changes in hydrology and agriculture that have followed from the construction of the Aswan High Dam have been associated with a rise in *S. mansoni* prevalence and a fall in *S. haematobium* prevalence (Abdel-Wahab and others 1979).

Control Measures

Schistosomiasis control is at present in a state of flux. During the 1960s the only control method shown to be effective was application of molluscicides to host snails, but more recently control programs have used several methods simultaneously and at high cost. Chemotherapy is likely to play an increasing role in the future.

Individual

Until recently, there was no drug suitable for mass chemotherapy on a large scale. The antimonial compounds used to treat schistosomiasis were toxic and required repeated intravenous or intramuscular injections spread over up to a month. Now there are several oral schistosomicides available, and others are undergoing trial. Metrifonate, only active against *S. haematobium*, causes negligible side effects and costs little. Two or three spaced doses are required. A single dose of oxamniquine treats *S. mansoni*, has few side effects, but is expensive. The chemotherapy of *S. japonicum* is unsatisfactory. A long course of niridazole is needed, with indifferent cure rates, but a very promising drug (praziquantel) is under field trial. Mass chemotherapy can now reduce prevalence and intensity of infection greatly; the duration of the reduction is limited (Costa, Katz and Dias 1980), and accompanying transmission control measures are necessary. Advantages of chemotherapy are its immediate effects on worm load and the disease in man. Cost is the chief defect, except for *S. haematobium*, and the cooperation of the population may be difficult to sustain in the long term.

Environmental

The intermediate host snails may be controlled either by rendering the habitat unfavorable to them or by the use of molluscicides. Environmental control has been most dramatically used against hosts of *S. japonicum*: in Japan, where irrigation canals were lined with concrete; in China, where labor-intensive methods of resiting canals and burial of the snails in the old canal were used; and in the Philippines, where it was shown that improved methods of irrigated field management both raised the production of rice and reduced the host snail populations in the fields. For the aquatic snail hosts of other schistosomes, such measures as channel straightening, weed clearance, and intermittent drying out of irrigation canals and drains have limited snail numbers. Biological control of snail populations by competitor species of snails has been shown in small specialized habitats and is claimed to have a significant effect on a larger scale, but as an operational control method has been little used.

Molluscicides have a long history, beginning with copper sulphate, but niclosamide (Bayluscide) and *n*-trityl-morpholine (Frescon) are the only ones in operational use now (McCullough and others 1980). They are relatively nontoxic to man, although they may harm fish and nontarget invertebrates. To achieve good snail kills the dosage needs careful control, and this can best be achieved where irrigation flows are appropriately managed. There is, as yet, no clear evidence of snail resistance to Bayluscide, even after prolonged application (Barnish and Prentice 1981). Although mollusciciding can stop transmission, the long survival of adult worms in man implies continuing the program for many years to maintain control or combining the molluscicide program with mass chemotherapy and improvements in water supply and sanitation (Hiatt and others 1980). Apart from altering snail habitats, environmental approaches to control consist either of preventing infected excreta from reaching the snails or of preventing human contact with infected water. Two control programs (in Brazil and St. Lucia), which provided water supplies, bathing or laundry facilities, and attempted to reduce infected water contact, have reduced transmission considerably, whereas other successful programs have included water supply and sanitation (Barbosa, Pinto and Souza 1971; Jordan 1977; Jordan and others 1978; Jordan and Unrau 1978).

The few recorded attempts to control schistosomiasis by providing excreta disposal facilities alone have been unsuccessful (Scott and Barlow 1938). This has been ascribed to people's failure to use the facilities because they were wrongly located — in villages, while defecation took place in the fields — or offensive, or ill-adapted to the cultural tradition or to use by children. One epidemiological model of schistosomiasis transmission (Macdonald 1965) has been interpreted as showing that excreta management is inefficient as a control method, even when latrines are used. However, this results more from the structure and assumptions of the model, rather than being a robust conclusion. Empirical testing of excreta disposal, when facilities are used, as a sole means of schistosome control is lacking. In general, one would doubt its efficacy, but as a concomitant measure with mass chemotherapy to prevent rapid build-up of the worm population after treatment it may have value, provided that those who "escape" the treatment regimen are not those who also fail to use excreta disposal facilities. Children below school age, and males who have recently left school and become migrants in search of work, are groups of particular concern.

Three factors mitigate against the efficacy of improved sanitation in schistosomiasis control. First, a single stool or urination may contain many eggs, and a single miracidium reaching a snail may give rise to several thousand cercariae. Therefore, the contamination of surface waters by excreta may have to be reduced to an extremely low level. Second, although it is possible to improve defecation behavior in some communities and to reduce the contamination of the environment by feces, it is very difficult to modify urination behavior. Therefore, the impact of sanitation programs on *S. haematobium* is likely to be markedly less than their impact on *S. mansoni* and *S. japonicum*. In addition, *S. haematobium* egg output is at its maximum in the early afternoon (Stimmel and Scott 1956), a time when children are likely to be playing in water and adults to be working in water. Third, those people in the community excreting most eggs are in the age group of 5–20 years. This group is likely to be less affected by sanitation programs than adults.

In summary, schistosomiasis control depends upon a carefully designed mix of chemotherapy, snail control, water supply, sanitation, and health education (Sandbach 1975; WHO 1980). The nature of this mix will be different in different places and must arise from detailed study of the local epidemiology of schistosomiasis. Some bizarre control strategies have been suggested, such as the maintenance of crocodile and hippopotamus populations in Lake Sibaya (Natal, South Africa) to discourage water contact (Appleton and Bruton 1979).

Some poor countries have achieved notable progress in schistosomiasis control by the sustained application of integrated control measures and the mobilization of popular support and participation. An example is China (Anon. 1977; Cheng 1971; Chung 1977; Sandbach 1977). Other countries have achieved substantial levels of control by specific antischistosome measures in the context of rising incomes and improved socioeconomic conditions. Examples are Japan, Puerto Rico, and Venezuela (Bhajan and others 1978; Negrón-Aponte and Jobin 1979; WHO 1973).

Occurrence and Survival in the Environment

The stages of schistosomes found in the environment are eggs, miracidia, and cercariae. Schistosome eggs are considerably less rugged and long lived than those of *Ascaris*, *Trichuris*, or *Taenia* worms. Schistosome miracidia and cercariae are fragile and must find a snail or vertebrate host within hours or they die.

In water

Schistosome eggs hatch rapidly on reaching water, and light and warmth speed hatching (Faust and Hoffman 1934; Maldonado, Acosta Matienzo and Vélez Herrera 1950; Miyairi and Suzuki 1913; Standen 1951). *S. japonicum* eggs will not hatch at temperatures below 3°C or above 38°C, with temperatures of 13–28°C being most suitable for hatching (Ito 1953). Standen (1951) found the *S. mansoni* eggs had an optimal temperature for hatching of 28°C. Hatching of *S. mansoni* eggs is reduced at salinities as low as 0.05 percent and ceases completely at 0.6 percent (Standen 1951). *S. mansoni* egg hatching is also inhibited by low dissolved oxygen levels (Kawata and Krusé 1966).

Miracidia swim in the water; if they come close to a snail, they are attracted to it and penetrate. If they do not encounter a snail, they may live for up to 3 days but are probably unable to penetrate a snail after a few hours (Faust and Meleney 1924; Miyairi and Suzuki 1913; Porter 1938). Experiments on *S. douthitti* miracidia showed that mean longevity falls with increasing temperature, from 11 hours at 8°C, to 7 hours at 20°C, and 1.5 hours at 35°C (Farley 1962). Kawata and Krusé (1966) found that *S. mansoni* miracidia in water at 26°C survived for up to 18 hours, with a mean of 6 hours. Miracidial survival is enhanced at pH values of around 7.5.

Schistosome cercariae are shed from the snail into the water and must find an appropriate vertebrate host and penetrate. Cercarial survival in water seldom exceeds 2 days and is temperature dependent. *S. japonicum* cercariae survive for over 7 days at 5°C and under 4 hours at 40°C (Jones and Brady 1947). As the length of time in the water increases, the ability of a cercaria to penetrate decreases, and it is probable that nearly all cercariae in warm tropical waters lose their ability to infect after less than 24 hours. *S. japonicum* cercariae tolerate pH in the range 5.5 to 8.4 (Jones and Brady 1947).

Schistosome cercariae are readily removed from drinking water by chlorination (Coles and Mann 1971; Frick and Hillyer 1965; Wittenberg and Yofe 1938) or by storage for 2 days.

In feces and night soil

The survival of *S. mansoni* and *S. japonicum* eggs in feces is of epidemiological importance. *S. mansoni* eggs in feces in South Africa all survived for 3 days, only half were hatchable after 6 days, and none after 8 days (Porter 1938). Experiments in Puerto Rico showed *S. mansoni* eggs survived for over 2 days in formed feces, but only 1 day in liquid feces, at 24–32°C. In formed feces at 7–10°C, survival was for over 7 days (Faust and Hoffman 1934).

S. japonicum eggs in feces may survive for longer than *S. mansoni* eggs. Early studies in Japan found that *S. japonicum* eggs in cow dung survived for up to 2–4 weeks (Miyairi and Suzuki 1913). Subsequent studies in Japan showed that *S. japonicum* eggs in wet rabbit feces survived for 20 days at 28°C, 113 days at 18°C, and 180 days at 8°C (Ito 1954*b*) *S. japonicum* eggs in the anaerobic fecal liquor of a biogas plant in China survived for up to 14 days in summer, 22 days in autumn, and 37 days in winter (McGarry and Stainforth 1978). The addition of urine to the feces, or drying to a moisture content of 5 percent, greatly reduces *S. japonicum* egg survival (National Schistosomiasis Research Comr•ittee 1959).

In urine

For *S. haematobium* eggs it is survival in urine, rather than feces, that affects transmission. Studies on *S. haematobium* eggs in urine at room temperature in South Africa showed that 60 percent were hatchable after 2 days, 10 percent after 3 days, 4 percent after 5 days, and none after 8 days (Porter 1938). Survival times were prolonged at cooler temperatures. Ito (1954*b*) studied *S. japonicum* eggs in urine. At 28°C they were unhatchable within a day in rabbit urine, 2 days in cow urine, and 3 days in human urine. Survival times doubled at 18°C and quadrupled at 8°C.

In sewage

Schistosomiasis is primarily an infection of poor people in rural areas, and such people typically produce no sewage. There are, however, some urban communities with flush toilets and sewerage systems where schistosomiasis prevalences are high enough to cause a detectable level of schistosome eggs in the sewage. An example was San Juan (Puerto Rico), where raw sewage contained 2 *S. mansoni* eggs per liter (Rowan and Gram 1959). Jones and others (1947) reported that *S. japonicum* eggs would not hatch in raw or settled sewage, but would hatch in raw sewage diluted to one-quarter strength in water or settled sewage diluted to one-third strength. Sewage with a low oxygen content seriously inhibited hatching and reduced the viability of *S. mansoni* eggs (Kawata and Krusé 1966).

Inactivation by Sewage Treatment Processes

Schistosome egg removal in sewage treatment processes has been little studied but is similar to *Ascaris* egg removal (chapter 23). The major difference is that many schistosome eggs will hatch during sewage treatment, especially in well-aerated environments such as activated sludge tanks or maturation ponds. Hatching promotes schistosome removal because the released miracidium is far more vulnerable than the egg and must find a suitable snail within a few hours or die.

Laboratory studies on *S. japonicum* eggs in sewage showed settling velocities of over 1 meter per hour for 73 percent of eggs (Jones and others 1947). Bench-scale trickling filter experiments showed higher removal of *S. japonicum* eggs at lower loading rates, and many eggs hatched during secondary sedimentation. Most eggs hatched after 24 hours aeration in a simulated activated sludge unit (Jones and others 1947).

Studies in Puerto Rico showed that 83 percent of *S. mansoni* eggs were removed during primary sedimentation and 99.5–100 percent by complete trickling filter or activated sludge plants (Rowan 1964*a*). It is possible that these very high removal rates were partly caused by some eggs hatching in the treatment plants and by the miracidia not being detected by the method used to detect eggs in the effluent. However large numbers of *Biomphalaria glabrata* snails were exposed for 3–6 hours to the plant effluents, but none became infected; although in an earlier study done at the same activated sludge plant when it was receiving a higher influent egg load *B. glabrata* snails did become infected by miracidia in the final effluent.

Schistosome eggs, miracidia, and cercariae should be completely removed by waste stabilization ponds. Laboratory experiments with *S. mansoni* eggs showed that hatching was inhibited, though not prevented, in anaerobic ponds and that hatching proceeded normally in facultative and maturation ponds. Miracidia survived for up to 6 hours (mean 2 hours) in an anaerobic pond and for up to 10 hours (mean 4 hours) in a maturation pond at 26°C. *Biomphalaria glabrata* snails survived for up to 42 days (mean 20 days) in an anaerobic pond and lived and reproduced normally in a maturation pond (Kawata and Krusé 1966).

Schistosome eggs entering a pond system will either die or hatch but will not be carried through to the effluent. Those that hatch will liberate miracidia that must find a suitable snail host rapidly or die. If the ponds are colonized by an appropriate snail species, some miracidia will encounter snails and penetrate. Subsequently numerous cercariae will be shed, but these must reach the outfall and find a human host within about 1 day. In a well-designed pond system, with an overall retention time of 15 or more days, cercariae will die long before they reach the outfall. Workers entering the ponds for maintenance purposes are at risk and need protective clothing.

Effluent chlorination to the level needed to have a satisfactory effect on excreted viruses (chapter 9) and bacteria (chapter 13) will also inactivate most schistosome eggs and all miracidia (Jones and Hummel 1947; Mercado-Burgos 1975; Rowan 1964*b*). Sand filtration of effluents will also remove schistosome eggs, but not all miracidia (Jones and others 1947; Newton, Figgat and Weibel 1948).

Inactivation by Night Soil and Sludge Treatment Processes

As with all helminth eggs, schistosome eggs in sewage treatment processes become concentrated in the sludge. Schistosome eggs are not long lived in feces, sludge, or night soil compared with *Ascaris*, *Trichuris*, or *Taenia* eggs, and any process that removed these other worm eggs will guarantee schistosome egg destruction.

S. japonicum eggs did not survive 21 days in sludge at 16–24°C or 9 days at 29–32°C (Newton, Figgat and Weibel 1948). *S. japonicum* eggs in digesting sludge at 24–30°C survived less than 25 days (Jones and others 1947). Kawata and Krusé (1966) found that 91 percent of *S. mansoni* eggs would not hatch after only 4 hours in waste stabilization pond sludge at room temperature, again suggesting that *S. mansoni* eggs are considerably less robust in the environment than are *S. japonicum* eggs. Normal anaerobic sludge digestion processes should therefore eliminate schistosome eggs if operated on a batch basis.

Sludge drying processes do not normally achieve the very low moisture contents needed to kill schistosome eggs by desiccation. Three weeks of sludge drying in warm climates should eliminate schistosome eggs irrespective of the moisture content reached (Jones and others 1947).

Schistosome eggs are readily killed by heating and are therefore eliminated by well-managed thermophilic

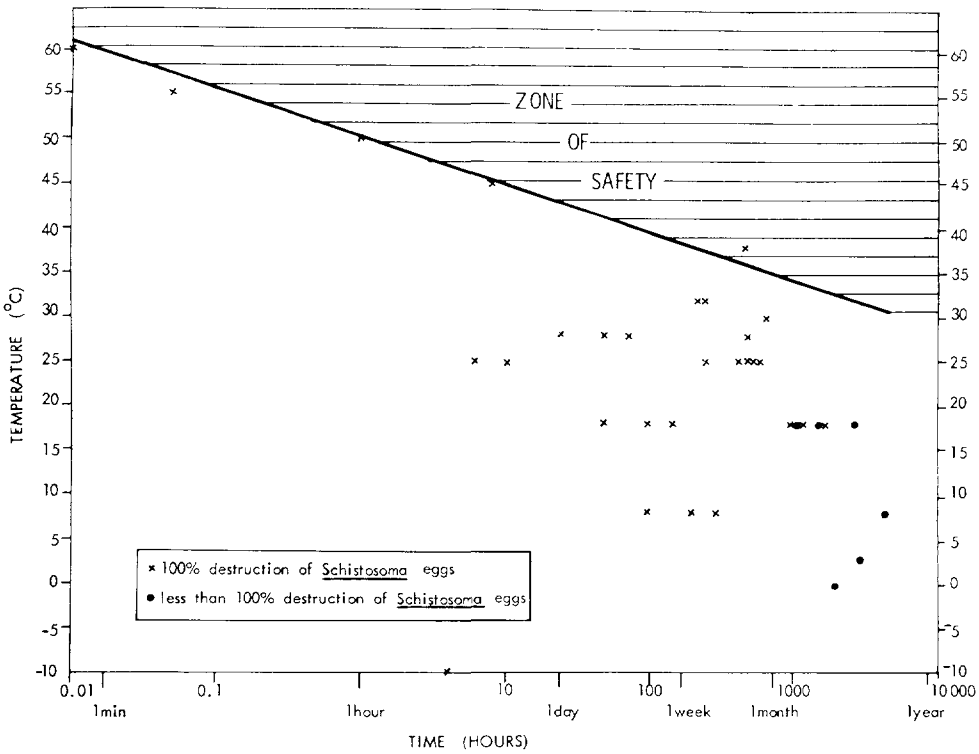

Figure 32-4. *The influence of time and temperature on* Schistosoma *eggs*. The points plotted are the results of experiments done under widely differing conditions. The line drawn represents a conservative upper boundary for death

composting processes. Data on the heat inactivation of schistosome eggs, from Ito (1954*a*) and other studies, are plotted on figure 32-4.

Work in China has shown that schistosome egg destruction in night soil may be promoted by the addition of urea, calcium cyanamide, or ammonium bicarbonate (Cheng 1971; National Schistosomiasis Research Committee 1959), and these add to the nitrogen value of the resulting fertilizer.

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