Section IV.
Excreted Helminths

22

Ancylostoma, *Necator*, and Ancylostomiasis

ANCYLOSTOMIASIS, or hookworm infection, is not only very common but also produces serious clinical consequences among a proportion of those infected. With the possible exception of schistosomiasis (chapter 32), it is the excreted worm with the greatest worldwide public health importance.

Description of Pathogen and Disease

Ancylostomiasis is an infection of the small intestine with one of the two species of human hookworms, *Necator americanus* or *Ancylostoma duodenale*. Incidental infections with animal hookworms such as *A. caninum*, *A. ceylanicum* and *A. braziliense* are not considered here, as they are unrelated to the disposal of human excreta. Ancylostomiasis is a comprehensively studied infection, and only a brief summary of information on the worms and the diseases they cause is given below. Several reviews are available, and Banwell and Schad (1978) and Miller (1979) are particularly recommended.

Identification

Ancylostomiasis is frequently symptomless. When it does produce illness and constitutes a public health problem, the most important features are anemia and its resulting weakness, debility and other consequences (Roche and Layrisse 1966). Gastrointestinal pain, transient cutaneous and pulmonary symptoms, and edema may also be experienced. In heavily affected endemic areas, ancylostomiasis produces its most severe clinical effects in older children and in young and middle-age adults, especially in those vulnerable groups subject to physiological iron losses, such as pregnant and lactating women or women suffering from abnormally heavy menstruation. In areas of very intense transmission, however, heavy worm burdens can be built up in early childhood, and in such cases there may be retardation of mental and physical development.

Hookworm is seldom recorded as a direct cause of death. Some grossly anemic individuals die of high-output heart failure. The disease is undoubtedly a common contributory cause of death when other normally nonfatal infections attack a severely anemic and debilitated person.

Numerous symptoms and signs cause suspicion of hookworm infection, but definitive diagnosis depends on finding eggs in fecal samples. Since the eggs of *N. americanus* and *A. duodenale* appear identical on microscopical examination, species recognition requires, in practice, either:

(i) The administration of a vermifuge, followed by collection of feces and microscopic study of the expelled adults, which are morphologically distinct, or
(ii) The cultivation of hookworm eggs to the filariform infective larval stage, when the two species can be differentiated.

Occurrence

Historically, human hookworm infections were probably confined to the eastern hemisphere, *N. americanus* occurring south of 20° north latitude, and *A. duodenale* north of 20° north latitude. In the past 500 years, population migrations, most notably those involving Spanish and Portuguese colonization in the New World and Southern Africa, led to the introduction of *A. duodenale* into these areas, as well as the importation of *N. americanus* to Portugal. At the same time, the slave trade from Africa to North and South America and the Caribbean islands led to the present widespread distribution of *N. americanus* in the western hemisphere.

The present geographical distribution of the hookworm species is given in figures 22-1 and 22-2. It

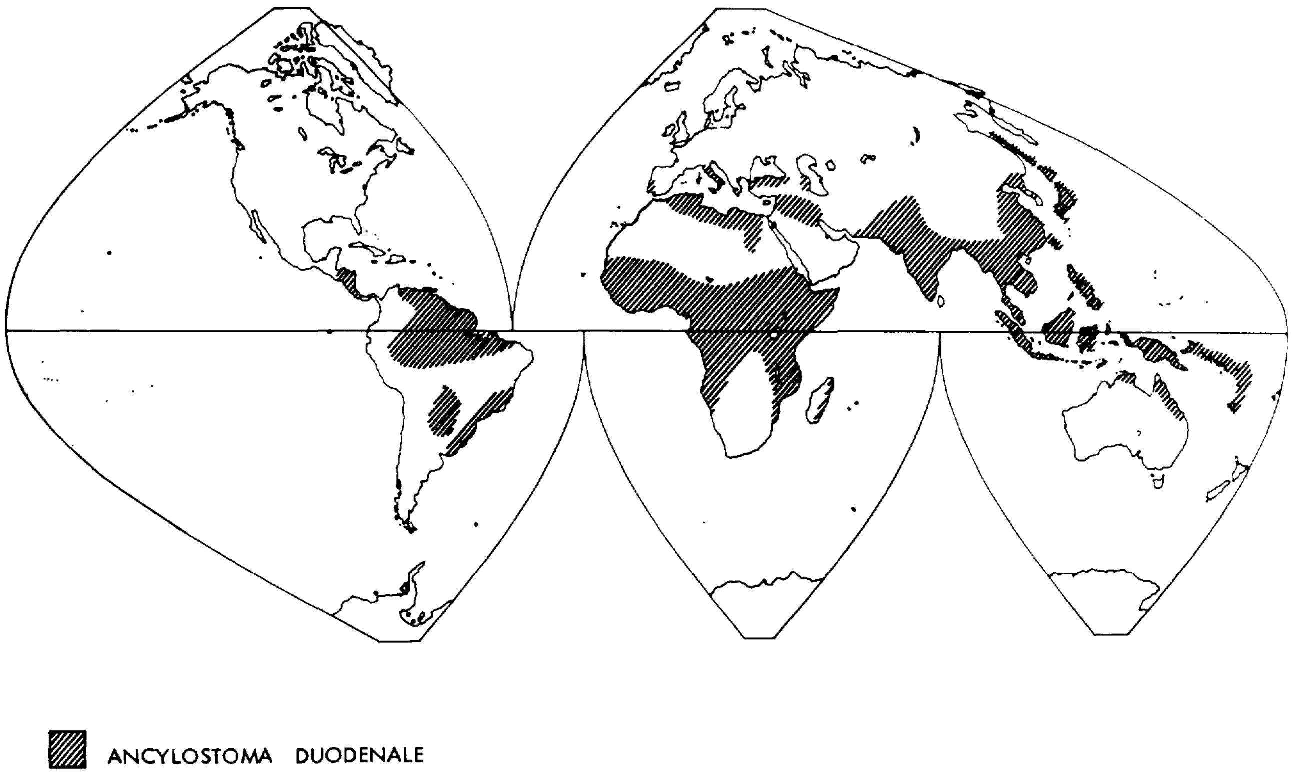

Figure 22-1. *Known geographical distribution of* Ancylostoma duodenale. The infection may occur in areas as yet unrecorded

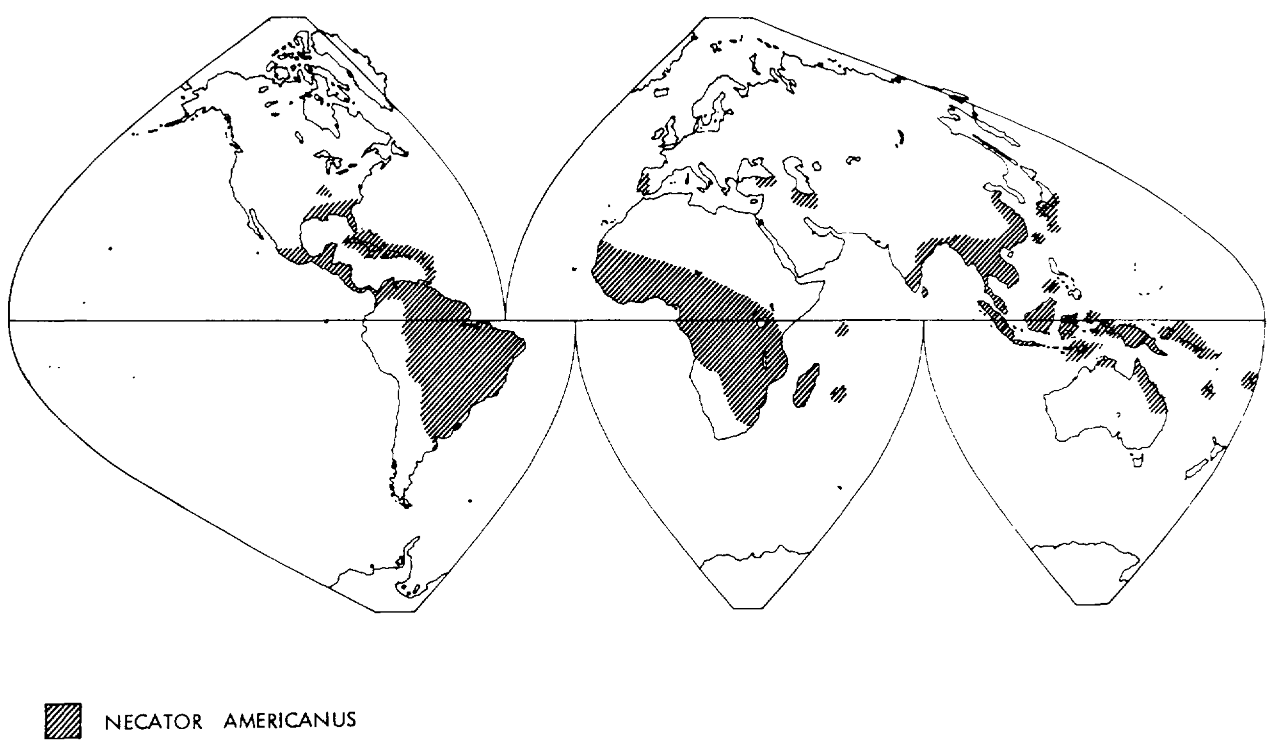

Figure 22-2. *Known geographical distribution of* Necator americanus. The infection may occur in areas as yet unrecorded

must be stressed, however, that many of the studies upon which these maps are based used egg detection techniques only and assumed the species identity of the parasites on the basis of existing knowledge for the locality. It is likely that future studies using adult worm recovery or cultivation of infective larvae will lead to considerable extensions of the geographical range of both worms. Furthermore, maps give no indication of the relative importance of each species in areas where both species are sympatric, nor do they indicate intensity of infection and, hence, clinical importance. It is essential that species prevalence and species intensity be determined for an area before the planning and execution of any control intervention.

Infectious agents

The two hookworms that infect man, *A. duodenale* and *N. americanus*, are diecious, sexually dimorphic roundworms belonging to the phylum Nematoda, order Strongylida, superfamily Ancylostomatoidea. The adult worms are small and off-white or rusty in color (figure 22-3). *A. duodenale* is somewhat larger than *N. americanus*, the males being 5–10 millimeters long and the females 10–18 millimeters, depending on the species. The eggs of *A. duodenale* measure 56–60 by 36–40 micrometers, and those of *N. americanus* are 64–76 by 36–40 micrometers in size.

A. ceylanicum, a hookworm of dogs, cats, and other animals, can infect man and develop to the adult stage. It has been reported to be of some importance in India, Surinam, West Irian (Indonesia) and elsewhere (Banwell and Schad 1978). *A braziliense* and *A. caninum*, the cat and dog hookworms, rarely develop to the adult stage in man, but their larvae can cause a creeping dermatitis called larva migrans.

Reservoir

Man is the reservoir for the human hookworms.

Transmission

Thin-shelled, ovoid, unsegmented eggs are discharged by the adult female worms into the lumen of the small intestine. The longer and stouter females of *A. duodenale* produce approximately twice the number of eggs per day (10^4 to 2×10^4) as do those of *N. americanus* (5×10^3 to 10^4). The eggs develop rapidly in the gut and are usually at the four- or eight-cell stage when evacuated in the feces. If feces are deposited in a suitable environment, the eggs hatch in 24–48 hours to give rise to rhabditiform first-stage larvae. Optimum

Figure 22-3. *The head (scolex) of an* Ancylostoma *under a light microscope.* Scale bar = 0.1 millimeters. (Photo: Wellcome Museum of Medical Sciences)

conditions for hatching and subsequent larval development are:

(i) Shade from strong sunlight
(ii) Soil of the right particle size, denseness and structure; ideally a light sandy loam
(iii) Adequate, but not excessive, moisture; both desiccation and water-logging are rapidly lethal to hatched hookworm larvae
(iv) A temperature between 28–32°C for *N. americanus*, and between 20–27°C for *A. duodenale*; above and below these temperature ranges, larval development is slowed down and it is completely arrested below 10°C and above 40°C
(v) Adequate decomposing organic material and microorganisms in the soil to provide a food supply for the developing larvae.

If conditions are satisfactory, the larvae undergo two moults outside the human body, on the third and fifth days of their free-living existence, giving rise to third-stage filariform larvae, which become infective to man about 6 days after hatching from the egg. These larvae normally survive for 3–6 weeks, and have a maximum life span of 15 weeks. Larvae have a maximum vertical range of migration of about 1 meter in suitable soil, but their lateral movement is restricted to about 0.3 meters and usually much less.

Infection of man occurs most commonly when the third-stage larvae penetrate the skin, usually between the toes or on the feet and ankles. In the case of *A. duodenale* only, the third-stage larvae can also infect man when they are ingested with unwashed, raw vegetables, onto which they can migrate from the soil. It is impossible to be certain of the relative importance of cutaneous and oral routes of infection with *A. duodenale;* probably they differ in different parts of the world with the food-eating and fertilizing habits of local populations. Experimental infections of man with *A. duodenale* are more easily produced by the oral than by the cutaneous route. Oral transmission of *N. americanus* is insignificant.

After penetration of the skin, larvae of both hookworm species enter small veins or lymphatic vessels and are carried to the heart and then to the lungs. *N. americanus* undergoes a period of development in the lungs, then ascends the bronchi and trachae, is swallowed, and reaches the small intestine in 24–48 hours after skin penetration; two further moults occur, about 1 day and 13 days after reaching the small intestine, *A. duodenale* undergoes the whole of its development in the small intestine, regardless of whether it enters the human body by the oral or cutaneous routes. Sexually mature fertilized females of both species begin egg laying between 4 and 8 weeks after infection.

Prepatent and incubation periods

The prepatent period (the interval between infection and the appearance of eggs in the stools) ranges from 4 to 8 weeks, with averages of 5 weeks for *A. duodenale* and 6 weeks for *N. americanus.*

The incubation period (the interval between infection and the development of symptoms and signs of illness) varies from a few weeks to several years, and depends on the number of worms that parasitize an individual, the individual's daily iron intake, body iron stores, and other blood losses. In light infections in healthy people, no evidence of illness may ever appear, although such individuals may be epidemiologically significant as egg-passers.

Period of communicability

Eggs will continue to be excreted for as long as there are adult female worms in the small intestine. Adult hookworms may live for up to 7 years in the case of *A. duodenale* and 15 years for *N. americanus* (Miller 1979). These are exceptional life spans, however, and 80 percent of worms survive for less than 3 years.

Resistance

Some degree of acquired resistance appears to develop with age and repeated reinfection, at least in some individuals. The problems of distinguishing between the effects of an immune response and the effects of varied exposure to infection are enormous in ancylostomiasis. Elderly people are frequently observed with high prevalence rates and high worm burdens. At present, the problem of immunity is of more interest to research workers than to those involved in investigating and controlling hookworm in field situations.

Epidemiology

Hookworm infections are extremely common and occur in many countries (figures 22-1 and 22-2). Perhaps 700 million persons are infected worldwide. There are many hundreds of reports of hookworm prevalence rates from almost every country in the world. A few are summarized in table 22-1. In some localities hookworm infects over half of the population, and it may be the most common intestinal worm. In other areas it is less common and is exceeded in prevalence by *Ascaris* or *Trichuris* or both.

There are major unexplained differences among communities in their prevalence of hookworm infection and in the relative prevalence of ascariasis, trichuriasis, and hookworm. These variations may occur even in a small geographical area—for example, within both northern and southwestern Iran (Ghadirian, Croll and Gyorkos 1979; Massoud and others 1980). These variations may sometimes be related to soil type and climate and the effect of these on egg and larval development and survival. They may also be due to differences in behaviour, settlement pattern, and agricultural practice. Because hookworm transmission is sometimes particularly vigorous in or near fields, rural prevalence rates are nearly always higher than urban rates (table 22-1). Rates are also higher in lower socioeconomic groups than among the more wealthy (table 22-1).

The distribution of hookworm infection among different age groups is typically fairly even, with the exception that prevalences are lower among children under 5 years old and sometimes in elderly adults. Ages of maximum prevalence vary considerably from community to community (table 22-1). Typically,

Table 22-1. *Prevalence of hookworm infection in fifteen countries*

Population	*Location*	*Age (years)*	*Prevalence (percent)*	*Age of maximum prevalence (years)*	*Source*
Bangladesh	Rural	All ages	29	ND	Mackay and others (1979)
Colombia	Urban	All ages	35	10–14 40–49	Faust and Mugaburu (1965)
Egypt	Rural	All ages	28	20–39	Chandler (1954)
Gambia	Rural	All ages	23	40+	Bray and Harris (1977)
Guatemala	Rural	1–5	12	ND	Pierce and others (1962)
	Urban (poor)	1–5	4	ND	
	Urban (wealthy)	1–5	0	ND	
Haiti	Rural	All ages	24	15–19	Raccurt, Vial and Pierre-Louis (1977)
India	Urban	All ages	8	ND	Biswas and others (1978)
	Rural	1–11	68	ND	Nawalinski, Schad and Chowdhury (1978*a*)
Iran	Rural	All ages	44–71	ND	Arfaa and others (1977)
	Rural	All ages	25	11–15	Massoud and others (1980)
	Urban	All ages	8	6–10	
Ivory Coast	Rural	7–14	73	ND	Nozais, Dunand and Le Brigant (1979)
Malaysia	Rural	6–12	43	ND	Lo and others (1979)
	Urban (poor)	4–6	5	13–15	Yan and others (1978)
	Urban (wealthy)	4–6	0	ND	
Papua New Guinea	Rural	All ages	68	20–29	Jones (1976)
South Korea	Urban	All ages	14	30–39	Seo and others (1969)
	Rural	All ages	19	30–39	
Taiwan	Rural	All ages	52	over 60	Hsieh (1970)
Thailand	Rural	All ages	61	ND	Bhaibulaya and others (1977)
Zambia	Rural	All ages	49	6–10	Wenlock (1979)

ND No data.

teenagers or young adults are the most infected, and prevalence rates are usually somewhat higher in males than in females. This may be because much transmission takes place outside the village at the communal defecation place or in the fields. Young men may therefore be most exposed, and immunological factors may prevent ever increasing prevalences among older men.

Risk of hookworm infection in some rural areas is linked to occupation. Thus, in rice-growing villages in northern Iran much transmission takes place in or near the rice fields, and the 10–40 age group has the highest prevalence rate (Ghadirian, Croll and Gyorkos 1979).

The immunological factors mentioned above have a greater influence on intensity of infection than on prevalence. Although prevalence rates are often highest in adults, average worm burdens, as estimated by average fecal egg outputs, are nearly always greatest in children.

Improved living standards and better sanitation have eradicated hookworm from some areas of Europe and North America and have made it rare in others. Nevertheless, in the USA an estimated 700,000 persons are infected (Warren 1974), and it is especially common in poor rural areas of the southeast. Hookworm prevalences of 10–20 percent are still recorded among schoolchildren in parts of Alabama, Kentucky, and Georgia. Hookworm control has, however, proved easier than control of the other major intestinal nematodes, and ascariasis and trichuriasis are typically more prevalent than hookworm in poor southern areas of the USA (Fulmer and Huempfner 1965).

Early studies on hookworm in Tennessee (Otto, Cort and Keller 1931) and Virginia (Otto and Spindler 1930) suggested that high hookworm prevalences were associated with sandy soils and that most transmission took place at moist and shady sites where older children and adults defecated. This was in contrast to *Ascaris* transmission, which was concentrated in the yard where young children defecated. It is unclear whether this model of transmission has global validity, although there is evidence for hookworm transmission in the fields in several countries, and the hard packed earth around houses is unsuitable for development of hookworm larvae.

It is possible that most percutaneous hookworm infection takes place at habitual defecation sites and during defecation. The heavy fecal contamination of the soil can lead to a high density of larvae, and these may survive for several days if the soil is moist, loose, and shaded. The act of defecation by a barefooted person ensures the prolonged contact between foot and soil needed for successful infection. Hookworm eggs and larvae can be transported by houseflies (Oyerinde 1976), and this may conceivably add to the transmission of *A. duodenale* by the oral route.

The seasonality of hookworm infection remains poorly understood. In areas where *A. duodenale* is endemic, a pronounced seasonal fluctuation in egg output has been recorded. In Assam and Bengal (Bangladesh and India), hookworms are lost during the period from the late monsoon (September) till February, and this worm loss is accompanied by falling egg outputs (Maplestone 1930, 1932; Nawalinski, Schad and Chowdhury 1978*a*, 1978*b*; Schad and others 1973). Hookworm egg outputs then rise sharply during the period March–May, before the start of the monsoon. The simple explanation of this would be an increase in transmission approximately 6 weeks before, during January–March. This is a dry hot period in Bengal, however, when larvae are rapidly killed in the soil and when soil surveys find few if any infective larvae (Banwell and Schad 1978). Rises in egg output before the rainy season have also been recorded in Taiwan (Hsieh 1970) and in Indian prisoners who were not exposed to transmission during the preceding few months (Maplestone 1930). It is postulated that hookworm larvae acquired during the rainy season of one year become dormant and subsequently develop to maturity before the next rainy season. This arrested development of *A. duodenale* remains controversial, and there are few data from areas other than Bengal. No similar seasonal phenomenon has been reported from areas where *N. americanus* is the only endemic human hookworm.

Control Measures

Many of the comments made about ascariasis control in chapter 23 apply equally to hookworm control. The major differences are, first, that the age of greatest prevalence of infection is typically higher in hookworm than ascariasis; second, that most ascariasis transmission may take place very near the home, whereas hookworm transmission typically occurs further afield; and, third, that *Ancylostoma* and *Necator* adult worms live very much longer in the intestine than *Ascaris*, and therefore the impact of reduced transmission will become apparent more slowly in the absence of mass chemotherapy. In some countries, for instance South Korea and the USA, hookworm infection has been easier to control than ascariasis, and this may be because it is less related to the hygienic behavior of young children and also because hookworm transmission is reduced by the increase in the practice of wearing shoes, where *Ascaris* transmission is not.

Individual

No special prophylactic drugs are available for hookworm infection. A valuable method of personal prophylaxis is the wearing of adequate footwear at all times when the skin might come into contact with infective larvae, especially in latrines themselves and in the immediate vicinity of human habitations, as well as during agricultural work. However, universal wearing of footwear is clearly not an immediately practicable proposition, for economic as well as customary reasons.

In rural Costa Rica it was found that hookworm prevalence was not associated with sanitation but was related to the use of shoes (Moore, de la Cruz and Vargas Mendez 1965). Males who always or sometimes wore shoes had a prevalence of 20–23 percent compared with 36 percent among males who never wore shoes. The figures for females were 13 percent for those who always wore shoes, 29 percent for those who sometimes wore shoes, and 39 percent for those who never wore shoes. Much transmission took place at customary defecation sites in coffee plantations.

Several drugs are effective against hookworm infections and are administered orally. Some of these drugs also treat infections with other common intestinal worms; for instance, mebendazole is useful for combined infections of hookworm, *Ascaris*, and *Trichuris* (Nagalingam and others 1976). Antihookworm drug therapy, in combination with oral iron therapy, should form part of any specific hookworm control campaign.

Mass chemotherapy will rapidly reduce the prevalence and intensity of hookworm infection. The benefits may be short lived, however, in the absence of improvements in sanitation and education, and precontrol prevalence rates and intensities of infection recur within 1–5 years of the drug campaign. Some studies on the fall and subsequent rise of hookworm prevalence following mass chemotherapy are listed in table 22-2.

Environmental

Improvements in excreta disposal facilities, in areas of high prevalence, have failed to achieve a marked impact (table 22-3). In some studies, a combination of mass chemotherapy and improved sanitation has failed to affect the prevalence in the long term but has caused a marked decrease in the intensity of infection. Other studies have indicated that the treatment of night soil used as a fertilizer, combined with mass chemotherapy, is effective in reducing the prevalence (and presumably the intensity) of infection. This is probably due to a reduction in transmission to people working in fertilized fields. It is to be expected that night soil treatment will be particularly effective in communities where prevalences are not extremely high, where most transmission occurs in the fields, and where hygiene in and around the home is relatively good.

There can be no doubt that a massive improvement in hygiene and excreta disposal would greatly reduce the prevalence and intensity of ancylostomiasis, as it has in Europe and North America. What is uncertain is whether limited and specific improvements can either reduce infection or maintain lower levels following a mass treatment campaign. Existing studies indicate not, but such studies have generally been very deficient in behavioral observation, and behavior is all important in the success of any excreta disposal program. Poorly used and maintained latrines will clearly not reduce ancylostomiasis, and they may act as new foci for transmission. Toddlers (1–3 years old) may continue to defecate around the home and transmit infection to their siblings. Even if excreta disposal is improved around the home, it may be unaffected in the fields or work places where transmission may continue unchecked. More work is required on this topic, and it should incorporate detailed observations on behavior and studies of community acceptance and attitude.

Available evidence indicates that excreta disposal programs will fail to control hookworm infection by themselves. They have a valuable ancillary role to play, however, in conjunction with:

- Mass repeated specific chemotherapy
- Mass oral iron therapy
- Increased use of footwear
- Intensive health education campaigns
- Development of basic health services and infrastructure.

This approach reduced the national prevalence of hookworm infection in South Korea from 39 percent in 1949 to 7 percent in 1972 (Soh 1973).

Table 22-2. *Some studies on the effect of mass chemotherapy on hookworm infection*

Country	*Drug*	*Source*
Bangladesh	Pyrantel	Mackay and others (1979)
Brazil	Chenopodium	Smillie (1922)
Costa Rica	Thiabendazole	Arguedas and others (1975)
Iran	Piperazine and bephenium hydroxynaphthoate	Arfaa and others (1977)
Japan	ND ND 1-bromo-2-naphthol	Kawagoe and others (1958) Kozai (1962) Kutsumi (1969)
Panama	Tetrachloroethylene and chenopodium ND	Cort, Schapiro and Stoll (1929) Sweet and others (1929)
Puerto Rico	ND	Hill (1925, 1926)
Thailand	Pyrantel	Bhaibulaya and others (1977)
Zaïre	Levamisole	Jancloes, Cornet and Thienpont (1979)

ND No data.

Table 22-3. *Some studies on environmental influences on hookworm infection*

Country	*Result*	*Source*
Brazil	Sanitation was effective in reducing hookworm intensity but not prevalence	Smillie (1922)
Costa Rica	Hookworm prevalence was associated with type of house floor and wearing shoes but not with sanitation	Moore, de la Cruz and Vargas Mendez (1965)
Egypt	A village receiving improved water supplies, latrines, and refuse collection had a lower prevalence (10 percent) of hookworm than a village with unimproved sanitation (28 percent)	Chandler (1954)
	Improved sanitation did not reduce hookworm prevalence	Scott and Barlow (1938)
Iran	Water and sanitation improvements had almost no impact on prevalence and a modest impact on intensity of hookworm infection; water and sanitation improvements plus regular mass chemotherapy added nothing to the impact of mass chemotherapy alone	Arfaa and others (1977)
Japan	Heat treatment of night soil using firewood led to reduced prevalence of hookworm infection	Katayama (1955)
	Night soil treatment, by heating with electricity, did not reduce hookworm prevalence, but delayed reinfection following mass chemotherapy	Kawagoe and others (1958)
	Night soil treatment with sodium nitrite and calcium superphosphate reduced but did not prevent reinfection of hookworm following mass chemotherapy	Kozai (1960*a*, 1960*b*, 1960*c* and 1962)
	Night soil treatment with thiabendazole reduced transmission of hookworm	Kutsumi (1969)
Panama	Sanitation delayed reinfection following mass chemotherapy	Cort, Schapiro and Stoll (1929)
	Sanitation delayed reinfection (especially in females) following mass chemotherapy	Sweet and others (1929)
Puerto Rico	Sanitation delayed reinfection following mass chemotherapy	Hill (1925, 1926)
Singapore	Poor families rehoused in modern flats had a hookworm prevalence of 1.0 percent compared with that of squatters (2.2 percent)	Kleevens (1966)
USA		
California	Rehousing mental patients in modern buildings interrupted hookworm transmission	Jeffery (1960)
Virginia	Sanitation appeared to be effective in reducing hookworm prevalence and intensity	Cort, Otto and Spindler (1930); Otto and Spindler (1930)

Occurrence and Survival in the Environment

Hookworm eggs and larvae in nature have been found mainly in soil at places where people defecate, or where night soil is applied to fields, and it is at these same sites that most percutaneous infection takes place. Eggs and larvae are also found on crops contaminated by night soil, sewage, or sludge. This pattern of contamination and infection has meant that there has been little interest in the possible wider dissemination of hookworm eggs and larvae in the environment. There has also been little interest in the survival of hookworm eggs in the environment because they are known to be less hardy than *Ascaris* eggs, and the latter therefore provide a better indicator organism for environmental helminthology.

In water

Hookworm eggs will tend to settle in water and eventually die in the bottom sediments. Their survival in seawater has been reported as under 5 hours, compared with over 30 hours for *Ascaris* eggs under the same experimental conditions (Livingstone 1978). In river water hookworm eggs can probably survive for a few weeks.

In feces and night soil

High concentrations of hookworm eggs are found in feces and night soil in endemic areas. Studies in Canton (China) in the 1920s recorded up to 85,000 viable hookworm eggs per liter of night soil (Oldt 1926). More recent studies from China found 840 eggs per liter (McGarry and Stainforth 1978).

Survival times of hookworm eggs in feces and night soil are considerably less than those of *Ascaris* eggs. In southern China, hookworm eggs in night soil and water mixtures were dead after 6–12 weeks (Oldt 1926). More recent work in China showed that hookworm eggs in biogas plant liquor at 9–18°C were reduced by 77 percent after 20 days, and by 99.5 percent after 70 days in winter (McGarry and Stainforth 1978). Similar results were reported by the Szechwan Research Institute (1974). Petrik (1954) considered that *Ancylostoma* eggs did not survive for more than 3 weeks in stored excreta at 20–22°C.

In sewage

At Daspoort (South Africa) settled sewage contained 6 hookworm eggs per liter (Nupen and de Villiers 1975). Very much higher concentrations may be expected in sewage from poor communities in developing countries. Sewage in Colombo (Sri Lanka) in the 1920s contained up to 330 hookworm eggs per liter (Hirst 1932). More recent data from Calcutta (India) showed that there were 22–750 hookworm eggs per gram of BOD_5 in the sewage (Bhaskaran and others 1956). Assuming a sewage strength of 250 milligrams of BOD_5 per liter, a hookworm egg concentration of 6–188 per liter may be computed. Lakshminarayana and Abdulappa (1969) detected up to 254 hookworm eggs per liter of sewage in Nagpur (India).

In sludge

Sludge from sewage treatment plants in areas of endemic hookworm may be expected to contain substantial hookworm egg concentrations. In Colombo (Sri Lanka) in the 1920s up to 96,000 hookworm eggs per liter of sludge from Imhoff tanks were recorded (Hirst 1932). In other areas hookworm eggs will be uncommon in sludge. A survey in the USA examined sludges from California, Georgia, Indiana, Kentucky, Montana, Ohio, and Wisconsin and found hookworm eggs only in the sludge from Frankfort, Indiana (Theis, Bolton and Storm 1978). An earlier survey of hookworm eggs and larvae in sludges in the USA was reported by Wright, Cram and Nolan (1942).

Hookworm eggs do not survive for long in sludge under tropical conditions. In Colombo (Sri Lanka) hookworm eggs could not be recognized microscopically after 43 days in sludge at 27°C and could not be cultivated after 23 days (Hirst 1932).

In soil

Under unfavorable conditions in soil (too hot, too cold, or too dry), hookworm eggs will either die or fail to develop and hatch. In either case they pose no risk. Under favorable conditions they will hatch and the resulting larvae will survive for less than 12 weeks.

Experiments on *A. duodenale* eggs in sterilized sandy soil in India (Vinayak, Chitkara and Chhuttani 1979) showed that in the hot dry months eggs hatched after 9–17 days, and the larvae survived for an average of 24 days. During the monsoon the eggs hatched after 5–12 days, and the larvae survived for an average of 90 days; in winter the equivalent periods were 45–62 days and 33 days. Clearly, warm wet conditions favor rapid hatching and prolonged larval survival. This was also found during experiments on *A. caninum* larvae on grass plots at Urbana, USA (Mark 1975). Mean larval survival times were <1 day during December–February, 7 days during March–July, and 24 days during August–November.

It may be expected that under field conditions larval survival in soil is shorter than recorded in laboratory experiments with sterilized soil. Even under ideal conditions (shaded, moist, sandy loam), over 99 percent of larvae die within 1 month (Banwell and Schad 1978).

The microhabitat of the hookworm larvae in soil is the moisture film surrounding the soil particles. If the larvae are near or on the surface and the moisture film dries, they will rapidly die from desiccation. In a loamy soil, larvae can move downwards to protect themselves from desiccation and bright sunlight. Following rain, they will move up to the surface again where they are at risk if the soil surface dries out very rapidly after a shower (Beaver 1953).

On crops

After rain, the moisture film on the surface soil particles may be continuous with the moisture films on low vegetation, and hookworm larvae can make their way up onto leaves and stems. If the plant surfaces dry out, the larvae will rapidly die unless they are secluded in the axillae or other moisture-retaining and sheltered sites. Vegetable contamination by hookworm larvae is of importance in *A. duodenale* endemic areas only, since it is this species that can readily infect via the oral, as well as the percutaneous, route.

In countries where night soil is widely used to fertilize vegetables, hookworm larvae are commonly isolated from market produce. In South Korea, for instance, Choi (1970) isolated hookworm eggs and larvae from leafy vegetables, watercress, and carrots.

Vegetables suspected of being contaminated may be soaked in a solution of iodine or other ovicidal chemical. Iodine concentrations needed to destroy hookworm eggs are roughly double those required to kill larvae (Thitasut 1961). It is simpler and more reliable, however, to soak the vegetables in warm water (60°C) for 10 minutes.

Inactivation by Sewage Treatment Processes

Large numbers of hookworm eggs enter sewage treatment plants in endemic areas. The fate of hookworm eggs during sewage treatment is similar to that of *Ascaris* eggs (discussed in greater detail in chapter 23). The two major differences are that hookworm eggs are less dense and that they may hatch.

Hookworm eggs are of similar size to *Ascaris* eggs but they have a lower specific gravity (1.055 compared with 1.11). Hookworm eggs therefore have a lower settling velocity and thus are less prone to removal by sedimentation processes (Cram 1943). Sedimentation is the main mechanism of removal of helminth eggs during sewage treatment, and therefore reported removals for hookworm eggs are typically a little less than those for *Ascaris* eggs.

Unlike *Ascaris* eggs, hookworm eggs may hatch during sewage treatment. Cram (1943) observed the hatching of hookworm eggs on trickling filter stones, in activated sludge tanks, and in drying sludge. Larvae will tend to stay in the liquid fraction and be carried out in the effluent; the eggs, however, tend to be concentrated in the sludge. The larvae may survive in sewage for up to 5 days (Cram 1943), which is quite sufficient for them to be discharged in the effluent and carried some distance.

Hookworm egg removal by sewage treatment is generally quoted as a percentage reduction in concentration between influent and effluent. This obscures the fact that most eggs not found in the effluent have not been destroyed but are merely concentrated in the sludge. Conventional sewage treatment plants have short retention times and operate at ambient temperatures and therefore do not destroy hookworm eggs. Their role is to transfer the eggs from the liquid fraction (the effluent) to the solid fraction (the sludge).

By septic tanks

Most hookworm eggs will settle in septic tanks and be eventually removed in the sludge. Bhaskaran and others (1956) reported 72 percent removal of hookworm eggs by a septic tank and trickling filter bed in Calcutta (India). McGarry and Stainforth (1978) reported studies in China on a biogas plant, which may be likened to a septic tank with a long retention time. The influent contained hookworm eggs in 87 percent of samples, with an average concentration of 840 per liter; the effluent contained hookworm eggs in 23 percent of samples, with an average concentration of 4 per liter.

By conventional treatment

Bhaskaran and others (1956) studied sewage treatment plants in the Calcutta area (India). Hookworm egg removals were 46 percent by 1.5 hours sedimentation (compared with 67 percent for *Ascaris*), 75 percent by 2 hours sedimentation (75 percent for *Ascaris*), 100 percent by an experimental trickling filter plant, and 81 and 96 percent by two activated sludge plants.

Panicker and Krishnamoorthi (1978) reported on hookworm egg removal by a variety of sewage treatment plants in India (table 22-4). Removal rates for hookworm eggs are consistently less than those for *Ascaris* eggs, and this is almost certainly due to the lower specific gravity of hookworm eggs and the resultant poorer removal by sedimentation.

By waste stabilization ponds

Waste stabilization ponds are able to eliminate hookworm eggs completely and reliably. Table 22-4 indicates that two pond systems in India achieved this, whereas two other pond systems did not. No design details are given by Panicker and Krishnamoorthi (1978) for these ponds, but it is certain that ponds not removing hookworm eggs are poorly designed or poorly operated or both. Earlier research in India had shown that some hookworm eggs will hatch in aerobic waste stabilization ponds and that the larvae may be

Table 22-4 *Reduction of helminth eggs by sewage treatment processes in India*

Process	*Hookworm*[a]	Ascaris	Hymenolepis	Trichuris trichiura	Taenia *spp.*
Two hours' sedimentation	80	96	90	90	75
Complete activated sludge plant	85	98	95	100	ND
Two complete trickling filter plants	82 92	95 96	80 89	93 100	ND ND
Pilot-scale biodisc plant with 1 hour of secondary sedimentation	50	79	60	60	ND
Pilot-scale oxidation ditch with secondary sedimentation	81	94	89	100	100
Pilot-scale aerated lagoon without secondary sedimentation	70	92	78	100	100
Four waste stabilization pond systems	93 88 100 100	100 100 100 100	100 100 100 100	100 100 100 100	100 100 100 100

ND No data.
Source: These data all taken from Panicker and Krishnamoorthi (1978).
Note: Percent reductions refer to influent compared with effluent. Most eggs not found in the effluent are concentrated in the raw sludge.
a. *Ancylostoma duodenale* and *Necator americanus.*

found in the effluent (Lakshminarayana and Abdulappa 1969). In a three-cell pond system with only 6 days' overall retention time, all hookworm eggs settled in the first and second ponds, but some larvae passed into the final effluent.

By tertiary treatment

Tertiary treatment of secondary effluents by filtration, land treatment, or lagooning will remove the remaining hookworm eggs (Cram 1943). Effluent chlorination will have little effect on hookworm eggs.

Inactivation by Night Soil and Sludge Treatment Processes

Hookworm eggs and larvae are less resistant to night soil and sludge treatment processes than *Ascaris* eggs. If the recommendations on *Ascaris* egg destruction are followed (chapter 23), the destruction of hookworm eggs is guaranteed.

The application to pasture or arable land of raw or inadequately treated sludges containing hookworm eggs is especially undesirable because, once eggs are in the soil, development will continue and infective larvae will be produced. The risks may be reduced by plowing the sludge deeply in, or by injecting it below the surface (Romanenko 1967), but if the soil is loose and moist hookworm larvae will still be able to rise to the surface.

By digestion

Sludge digestion at temperatures below 40°C does not eliminate hookworm eggs (Petrik 1954). Cram (1943) found that hookworm eggs did not develop in digesting sludge but that they could survive for up to 64 days at 20°C and 41 days at 30°C.

By ovicides and larvicides

The addition of chemical ovidices and larvicides to night soil and sludge is a treatment option. Thiabendazole (Kutsumi and Komiya 1965) and several other chemicals (see, for instance, Sturrock 1966) have been tried or proposed. Hookworm eggs are considerably less resistant to ovicides than *Ascaris* eggs, and the treatments found effective against *Ascaris* (table 23-4) will certainly eliminate hookworm. For instance, the concentrations of thiabendazole necessary to destroy helminth eggs in 3 days in night soil at 15°C were 100 milligrams per liter for *Ascaris*, 6 milligrams per liter for *Trichuris*, and 1.6 milligrams per liter for hookworms (Kutsumi and Komiya 1965). This approach to night soil treatment will, however, be impractical and unaffordable in many circumstances. Of greater interest is the possibility that some chemical fertilizers when added to night soil or sludge may have the combined effect of enhancing the agricultural value of the product and eliminating hookworm eggs and larvae. Oldt (1926) in China found that ammonium sulphate, lime, and gypsum were effective, whereas Penso (1933) in Italy preferred ferrous sulphate. In Japan, the application of sodium nitrite to night soil that had been acidified by adding calcium superphosphate controlled hookworm eggs in the night soil and also delayed reinfection in the community following mass chemotherapy (Kozai, 1960*a*, 1960*b*, 1960*c* and 1962).

By drying

Cram (1943) found that hookworm eggs hatched in drying sludge and that the larvae remained viable for up to 62 days until the moisture content of the sludge had fallen to 10 percent. At warmer temperatures, hookworm elimination in sludge is more rapid; Hirst (1932), working in Sri Lanka, suggested that 1 month of sludge storage would eliminate hookworm eggs.

By heating

Ascaris eggs are considerably more hardy than hookworm eggs, and time-temperature combinations that destroy the former (see figure 23-2) will certainly destroy the latter. Data on time-temperature combinations required to destroy hookworm eggs are presented in figure 22-4. Table 22-5 presents data on the upper and lower temperature tolerances for *A. duodenale* and *N. americanus* eggs and larvae. Clearly, eggs are considerably more resistant than larvae to both heat and cold. Also, *N. americanus* is more tolerant of higher temperatures and *A. duodenale* of lower. This is one underlying factor in their geographical distribution.

The most practical method of achieving the elevated temperatures needed to destroy hookworm eggs and larvae is by composting as described below. In Japan, heating night soil with firewood (Katayama 1955), or with cheap-rate night-time electricity (Kawagoe and others 1958), has been found to kill hookworm eggs in night soil and to reduce hookworm infection in the community. These techniques use large amounts of energy, however, and are not generally applicable.

By composting

Composting of night soil or sludge with garbage, woodchips, or other suitable carbonaceous bulking material is highly effective in eliminating hookworm

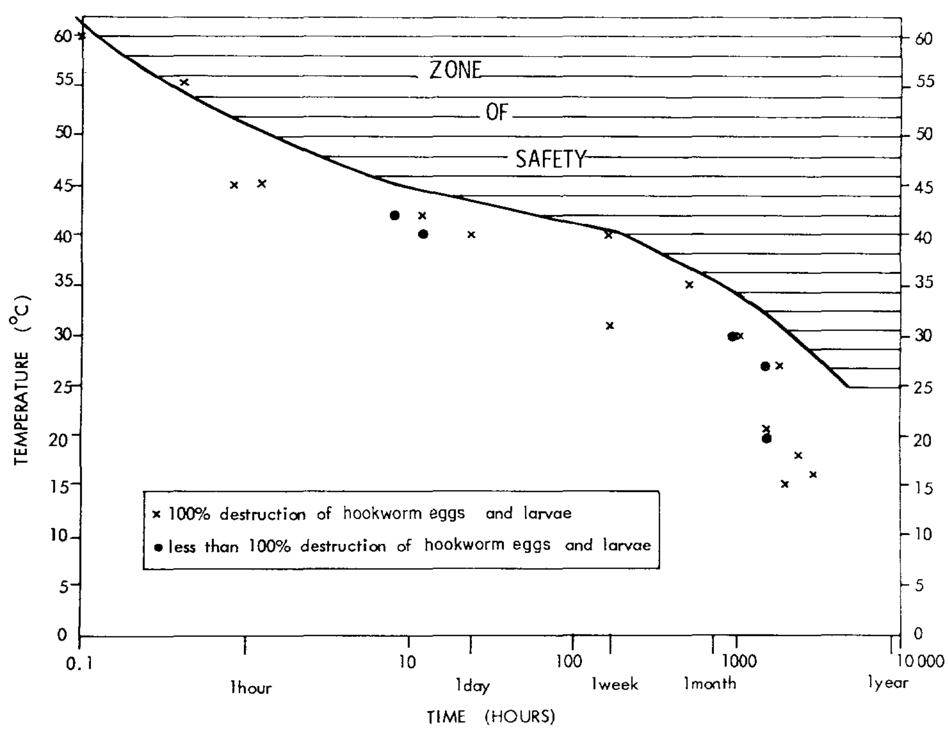

Figure 22-4. *The influence of time and temperature on hookworm eggs and larvae.* The points plotted are the results of experiments done under widely differing conditions. The line drawn represents a conservative upper boundary for death. See also table 22-5

Table 22-5. *Tolerance of hookworm eggs and larvae to high and low temperatures*

Temperature limit	Ancylostoma duodenale		Necator americanus	
	Eggs	*Larvae*	*Eggs*	*Larvae*
Upper	50°C for 5 minutes 60°C for 1 minute	45°C for 5 minutes 50°C for 1 minute	50°C for 5 minutes 65°C for 1 minute	50°C for 5 minutes 55°C for 1 minute
Lower	−5°C for 9 hours (41 percent dead after 3 hours)	0°C for 7 days	−5°C for 9 hours (93 percent dead after 3 hours)	5°C for 1 day

Note: See also figure 22-4.

eggs and larvae. Time-temperature combinations shown in figure 22-4 must be achieved throughout the compost pile. Hookworm eggs may hatch before temperatures have risen, and the resulting larvae may migrate to the cooler edges of the pile. Regular turning or good pile insulation is therefore required.

Studies on hookworm elimination by composting have been reported from China (Hou and others 1959; Oldt 1926), Sri Lanka (Nicholls and Gunawardana 1939), and the USSR (Gudzhabidze and Lyubchenko 1959). Other studies are reviewed by Petrik (1954) and Wiley (1962). *Ascaris* eggs are considerably more resistant to composting than hookworm eggs; in areas where both nematodes are endemic, it therefore is preferable to monitor *Ascaris* eggs in the final compost.

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