

CONTROL OF SOIL-TRANSMITTED HELMINTHS

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INTRODUCTION

GENERAL CONSIDERATIONS

Through co-ordinated investigations and organized control programmes, significant progress has been made towards the management of health problems resulting from the blood flukes, filariae, *Trichinella*, *Echinococcus* and *Taenia*. It has been possible also to bring under group discussion some of the research problems related to the control of these helminths. It is to be noted that each is transmitted through intermediate hosts, a circumstance which provides opportunities for interrupting the life-cycle of the parasite by dealing primarily with its biological vector. By destroying the vector or the parasite within it, or by barring contacts between the vector and the human population, a high degree of protection against infection can be accomplished without the participation of the population being protected.

From the standpoint of their influence on individual health and group productivity throughout the world, the soil-transmitted intestinal nematodes—roundworms (*Ascaris lumbricoides*), whipworms (*Trichuris trichiura*) and hookworms (*Ancylostoma duodenale* and *Necator americanus*)—rank highest among all the helminths, and their prevalence in different communities serves as an index of socio-economic status. *Ascaris* and *Trichuris* affect the health of children especially; the former being a frequent cause of complications and of death in many parts of the world, the latter causing severe and stubborn dysentery. The hookworms are recognized as an important cause of anaemia, particularly in older children and young adults. The obvious high rank of hookworm infection as a cause of debilitating disease placed it first among the helminthiases to be attacked on a wide scale.

Thus far control efforts against the common intestinal nematodes have been relatively disappointing, chiefly because no practical way has been found to interrupt the exogenous segment of the life-cycle, and no really effective anthelmintic or prophylactic drug has become

available for interrupting the endogenous phases of the infection. While it is proper to acknowledge and to analyse the causes of past failures, those disappointing experiences cannot legitimately be used as an apology for inaction or as a pretext for delaying action on this important aspect of public health programmes.

NATURE OF SOIL-TRANSMITTED HELMINTHS

In the life-cycle of *Ascaris lumbricoides*, *Trichuris trichiura*, *Ancylostoma duodenale*, *Necator americanus*, and some other helminths which less commonly infect human beings, the soil receives (by faecal contamination) stages which are not infective; the soil provides conditions under which development to the infective stage can take place; and the soil provides protection for the infective stage for a period during which it fortuitously may be brought into contact with a susceptible individual whom it may enter by the mouth (*Ascaris*, *Trichuris*, *Ancylostoma*) or by the skin (*Necator*, *Ancylostoma*). Thus the soil serves these parasites in essentially the same manner as an intermediate host.

Significantly, as some other helminths require specific intermediate hosts, the soil-transmitted worms require specific types of soil and they tolerate relatively narrow limits in the range of physical conditions within the soil. A general explanation for the wide distribution of *Ascaris*, *Trichuris* and the hookworms and for their prevalence in areas with poor sanitation is that their requirements of climate and soil are essentially the same as those of man himself wherever he is largely dependent upon locally grown wild or crop plants for food.

Fundamentally, the endemicity of the soil-transmitted helminths depends upon the presence of infected individuals, habitual or continual faecal contamination of the soil, a favourable soil environment (temperature, moisture, soil-texture) for the development of infective stages, and frequent contact between infective soil and uninfected individuals. Theoretically, therefore, control of any of these worms might be accomplished by removing infection (and reinfection before patency) from all individuals of the population, by complete prohibition of faecal contamination of the soil for a period equal to the maximum life expectancies of the worms and their infective stages, by rendering the soil in contaminated areas unsuitable for development of infective stages, or by barring contact with infective soil for a period long enough to ensure natural loss of infection from the people. Actually, in situations where the control of soil-transmitted infections is most needed, each of the theoretically possible approaches to control is obstructed by hurdles which are at present almost insurmountable.

NATURE OF CONTROL EFFORTS

Organized efforts to combat hookworms and similarly transmitted helminths have been extensive and have in diverse ways benefited millions of people in many parts of the world. They have been directly responsible for the establishment of public health departments and general health services, for the installation of latrines, the administration of anthelmintics, and the dissemination of health information which has served to influence individual and community attitudes favourably on matters of sanitation, nutrition and other aspects of disease prevention. In general, however, their direct effects on the prevalence of infection have been disappointingly slight and transient.

Analysis of prevalence data on *Ascaris*, *Trichuris* and hookworm infections, with reference to either the need for or the results obtained from organized programmes of control, usually shows a close relationship between socio-economic status and intensity of infection. The most advanced communities and the most favoured members within the community are almost invariably the least frequently and least heavily parasitized. Likewise, in considering the prevalence of infection among the members of any socio-economically advancing large community, reductions in the rate of infection in successive decades are directly proportional to the degree of advancement.

In the south-eastern United States of America, where the gradually falling rates of infection with hookworms and other intestinal helminths have been observed and recorded periodically over the past fifty years, campaigns against the hookworm have been carried out more or less continuously. Although the effects of these control programmes, apart from other influences, cannot be measured precisely, most observers agree that the benefits derived from them have been to a large extent indirect—i.e., they have made relatively small though important direct contributions to the reduction in hookworm prevalence, but without marked progress in other aspects of community development, the frequent mass surveys, treatment of infected individuals, installation of latrines and propaganda for preventive measures would have had little lasting effect.

Some twenty years ago, recognition of the transient nature of the benefits of mass hookworm campaigns and the observed interrelationships between community development and parasite prevalence, along with newly developed concepts of helminthic diseases in relation to worm burden and nutritional status, brought about a new approach to the investigation and control of hookworm disease (Andrews, 1942a, 1942b). The new plan was formulated on five basic assumptions. (1) With the tools and techniques at present available applied to open communities in which the people cannot be placed under strict

individual control, eradication of hookworm and similarly transmitted infections in highly endemic areas is not possible. (2) Light infections are generally well tolerated and the mere presence of infection does not constitute evidence of detrimental effect upon health and economic productivity. (3) Favourable conditions of soil, moisture, and temperature are essential to the transmission of infections and, since these factors are variable from place to place, damaging infections do not occur equally in all communities without sanitation. (4) Infections that are of damaging intensity are detectable among those that are not. (5) While the administration of available anthelmintics frequently fails to eradicate an infection, reducing the worm burden to tolerable levels is relatively easy in most cases.

With a selective type of control programme based on these assumptions, it was deemed possible to control the disease independently of the infection, that is, the disease's retardation of socio-economic progress could be prevented by concentrating control efforts on those communities in which damaging infections were most prevalent, and by selecting for treatment those individuals whose infections were contributing to, or might contribute significantly to, a condition of suboptimal health. This type of programme, of course, could be effective and practical from the standpoint of lasting values only if carried out as a co-ordinated part of a comprehensive programme of community improvement.

The selective type of programme was instituted in Georgia in the USA in 1940. Though sometimes reluctant to accept it, on the grounds that the total infectiousness of the population was not affected and the probability of reinfection was therefore not reduced, different administrators since that time, after analysis of the costs, results, and alternatives, have accepted the programme and maintained its essential operational features.

Elsewhere in the Americas and in other parts of the world, hookworm control programmes have followed in large part the pattern of survey, treatment and latrine installation that was established by the Rockefeller hookworm campaigns of the 1910-30 period. In many places—including some areas of the south-eastern United States of America where hookworm disease is still to be found among rural people—because of the acknowledged futility of attempting eradication and the assumption that in due course the problem will vanish, essentially nothing is being done in an organized way.

THE PROBLEM

Although the vast literature on the soil-transmitted helminths would seem to contain sufficient information to permit some progress towards

their eradication, there is an apparent need for new facts on which sound decisions can be made concerning the questions where, when and how to develop control programmes that can be regarded as successful even when they fall short of eradication. In the discussion to follow, those facts, or supposed facts, which seem to be most pertinent to the control of hookworm and other common soil-transmitted helminths will be summarized with reference to the several worms as a group and as they apply particularly to each type of worm. Also, mention will be made of some of the problems which appear to be susceptible of solution and may therefore provide a basis for more complete and accurate concepts of the diseases produced by these worms, and for more effective methods of control under divers circumstances.

CONSIDERATIONS IN CONTROL

DISTRIBUTION AND PREVALENCE

In general, ascariasis, trichuriasis and ankylostomiasis, individually or in combination, are important public health problems throughout the tropical regions and are among the major causes of illness in all under-developed areas of subtropical regions. The prevalence and intensity of infection vary directly with the degree of insanitation, and the extent to which endemicity extends into the cooler areas depends upon the amount and frequency of faecal contamination of soil in the immediate vicinity of permanent habitations.

In considering the probable extent of endemicity, it is to be borne in mind that under conditions of crowding and poor housing, infections may be prevalent in areas with apparently good sanitation. The presence of latrines or even the general use of flush toilets in neighbourhoods and larger communities where the soil and climatic conditions are especially favourable may not completely stop transmission, especially among young children. Promiscuous defecation by toddler-age children and the discharge of faeces-bearing wastes from "sanitized" houses in the immediately adjacent soil is often sufficient to maintain a high level of endemicity (Headlee, 1936). Moreover, it has been shown that in areas where the soil is generally unsuitable for *Ascaris* and *Trichuris* transmission, the soil immediately surrounding habitations is favourably conditioned by the accumulation of organic debris discharged from the houses (Beaver, 1952b). Soil conditioning in this manner is apparently not an important factor in the transmission of hookworm infection since it occurs less frequently in children under three years of age. The explanation for this is that hookworm eggs are more frequently destroyed before being discharged from the houses into the surrounding soil and the infective larvae persist in the soil for relatively short periods as compared with the infective eggs of *Ascaris* and *Trichuris* (Beaver, 1953). The latter may be transported from inside to outside the house and *vice versa* repeatedly without losing their infectivity. Thus the younger children and to a lesser extent

older members of the family easily become infected and continue the cycle.

The importance of ascariasis as a cause of disease and of death among children has been emphasized in numerous reports; in a highly endemic area in Ceylon, it has been reported as the third-ranking cause of death among children (Fernando & Balasingham, 1943). Occasionally among adults it is a cause of death (Beaver & Danaraj, 1958), and under certain conditions it is major cause of pulmonary disease among people of all ages (Vogel & Minning, 1942; Loeffler et al., 1948; Hemming, 1956). Though much less frequently reported, clinically severe trichuriasis is known to be common in Panama, the East Indies, Cuba, Puerto Rico, India, South Africa, Chile, the Philippines and the south-eastern United States of America (Jung & Jelliffe, 1952). It is doubtless a common but unrecognized cause of diarrhoea and severe dysentery in most areas where the rates of infection are high. Hookworm disease in the form of anaemia is well known as a debilitating disease in warm areas of the world with no or poor sanitation, and under special conditions it may extend into the cooler regions. Rarely do any of these infections fail to have a significant adverse effect on the general health and community development in areas where they are prevalent.

High prevalence rates for one or more of the soil-transmitted worms have been reported in recent years from all major regions of the world. In the absence of reliable reports to the contrary, it can be assumed that throughout the tropics and subtropics the intestinal worms are among the important retarding influences on community development.

In Puerto Rico, hookworm disease is no longer considered a major public health problem (19%-41%), but in five of six areas recently sampled (Maldonado & Oliver-Gonzalez, 1960) the rates ranged from 30% to 50% for *Ascaris* and from 72% to 87% for *Trichuris*; egg-counts indicated heavy worm burdens in about 15% of individuals with *Ascaris* and 12% with *Trichuris* infections; whereas only 2% of the hookworm infections were heavy (10 eggs/mg faeces and over).

In China, where the intention is to eradicate the infections from the entire population, recent sampling has shown rates of 30%-97% for *Ascaris* and 30%-90% for hookworm; *Trichuris* is said to have ubiquitous distribution (Hou et al., 1959). Complications with ascariasis are extremely common in China, and liver abscess due to invasion of the liver by adult worms entering *via* the bile duct is two to three times as common as that caused by amoebae.

In Mauritius, where anaemia is especially prevalent, hookworm infection was found in about half the general population and in 88% of anaemic patients (Stott, 1960, 1961). In the same groups, the rates for *Ascaris* and *Trichuris* were 32% and 40% respectively; half the anaemic

patients had *Ascaris* infection (Stott—unpublished data). In another island group in the Indian Ocean, Seychelles, in the age-groups from 1 to 4 years and upwards *Ascaris* was found in half to three-fourths of the people and *Trichuris* in nearly 90%; hookworm rates were 46% in the plateau and 28% in the hilly regions (Spitz, 1960).

Examination of two groups including both urban and rural populations in Bolivia (Asunción and Villarica) indicated that hookworm infection was very common (50% and 61% respectively), whereas *Ascaris* and *Trichuris* were of minor importance, the respective rates being for *Ascaris* 3% and 16%, and for *Trichuris* 1% and 10% (Hilburg, 1955). Similarly, in the Fort Rosebery region of Northern Rhodesia samples of children from 12 localities showed hookworm infections in 30%-52%, while the highest rate for *Ascaris* was 9% and *Trichuris* was almost lacking, being found in 1% of 320 stool samples in one locality. In groups of schoolchildren in a nearby swampy area, however, *Ascaris* was common (59%-69%) although *Trichuris* was not (0-2%); hookworm rates were only slightly lower than elsewhere (22%-33%) (McCullough & Friis-Hansen—unpublished data, 1959).

In two districts of West Pakistan (Shakargarh and Lahore) some samples of the population showed hookworm infection in more than 30% but none of the egg-counts was above 2000 per gram.¹ It is noteworthy that in Shakargarh the infections were as frequent among children 2-5 years of age (23%) as among other age-groups (20%-24%). Data on *Ascaris* and *Trichuris* were not reported. Reports of surveys recently carried out in Egypt and the Eastern Mediterranean countries likewise show that hookworm infection is widespread, though concentrated here and there, and that the intensity and the rate of infection may not be proportional. Among schoolchildren in Syria rates at Deir ez Zor were, mostly above 50% but the highest egg-count recorded was 2000 per gram.¹ In the middle and southern parts of Iraq hookworm rates among schoolchildren were found to range between 10% and 20% in most districts but reached 38% in some.¹ *Ascaris* has been shown to be prevalent almost everywhere in that general region, infection rates above 50% being common. *Trichuris* is often omitted from discussions of intestinal parasite problems, presumably because its importance is not appreciated.

Statistical yearbooks and annual medical reports, though incomplete and occasionally misleading, indicate in a general way the relative importance of ankylostomiasis in various regions. In Asia and Oceania the disease has significant rank in North Borneo, Ceylon, Fiji, Japan and Malaya; in Africa reported infection rates are high in Angola,

¹ Data taken unpublished WHO working documents.

RECENT PREVALENCE RECORDS (PERCENTAGES) OF ANKYLOSTOMIASIS, ASCARIASIS,
AND TRICHIURIASIS IN VARIOUS REGIONS

Region	Ankylostomiasis	Ascariasis	Trichiuriasis	Reference
Korea	37-46	81-82	78-81	Brooke et al. (1956)
China (mainland)	30-90	30-97	-	Hou et al. (1959)
Taiwan	79-94	20-72	59-89	Frick et al. (1956)
Thailand (2 areas)	3-28	20-48	1-12	Sadun (1953, 1955)
Philippines (Palo)	60-90	80-82	87-90	Pesigan et al. (1958)
New Guinea (5 areas)	94-98	0-70	4-88	Beurup & Lawrence (1950)
Tahiti	38	13	44	Kessel et al. (1954)
Lebanon (urban)	-	22	16	Salam et al. (1955)
Jordan (2 areas)	-	51-78	44-78	Alicata & Dajani (1955)
N. Egypt (13 areas)	2-70	2-79	0-27	Kuntz et al. (1958)
N. Rhodesia (12 schools)	30-52	0-9	0-1	McCullough & Friis-Hansen (unpublished data, 1959)
Natal, S. Africa (3 areas)	4-6	26-50	39-60	Elsdon-Dew & Horner (1958)
Mauritius (1952-55)	25-55	28-36	33-49	Stott (1961)
Seychelles (ages 5-60)	23-35	43-78	82-95	Spitz (1960)
Puerto Rico (6 areas)	19-41	30-50	72-89	Maldonado & Oliver-Gonzalez (1960)
Surinam	8	42	9	Blumberg et al. (1953)
Costa Rica (students)	1-6	6-7	31-33	Jimenez-Quiros et al. (1958)
Peru (Iquitos)	91	75	81	Gonzalez-Mugaburu (1955)
Bolivia (2 areas)	50-61	3-16	1-10	Hilburg (1955)

Cameroun, Republic of the Congo (Léopoldville), Kenya, Ruanda-Urundi, Somaliland, Sudan, Tanganyika, Uganda and Zanzibar; and in the Americas ankylostomiasis is among the more prevalent reportable diseases in Colombia, Costa Rica, Dominican Republic, Paraguay, south-eastern United States of America, Venezuela and Trinidad.

The above examples are sketchy and incomplete but they serve to re-emphasize the fact that while infections with the soil-transmitted helminths are spotty in distribution and vary greatly in intensity in different localities, they are almost universally endemic in broad areas of under-developed countries with a mild or hot climate (see the accompanying table). The problem of the soil-transmitted helminths is obvious, at least to all public health leaders. The problem is not so much to develop a consciousness of the needs for control; it is instead to determine in a selective manner where the helminth problem is so acute as to require remedial measures, to select areas in which the more permanently beneficial approach—prevention—is in order, and to determine the most effective remedial or preventive measures available for meeting the needs of particular localities.

INFECTION *VERSUS* DISEASE

One of the principles of helminthology is that worms are relatively well tolerated when present in small numbers, but that any species may be damaging to the host if present in large numbers—i.e., the amount of damage produced by a worm infection depends in large part upon the number and species involved. With reference to ascariasis and ankylostomiasis, this principle applies to all phases of infection, the invasive as well as the intestinal stages. Data on prevalence only, therefore, are incomplete as an index of morbidity, and they have value chiefly in defining the geographical boundaries within which the disease may be found.

Usually the clinical manifestations of ascariasis, trichuriasis and ankylostomiasis are readily recognized in their more severe forms. In almost all instances, however, laboratory studies are essential to accurate diagnosis and proper evaluation, owing to the multiplicity of causes of the most common manifestations. Pulmonary ascariasis and ankylostomiasis cannot readily be distinguished from other types of pneumonitis, bronchiolitis and bronchial asthma, and they have frequently been mistaken for early tuberculosis; the prepatent (biological incubation) and early patent intestinal phases of hookworm infection produce much the same complaints as enteritis, duodenitis and duodenal ulceration resulting from other causes; hookworm infection, as is now well

known, is only one of several causes of microcytic hypochromic anaemia; ascariasis apparently may either produce or simulate malnutrition, and such complications of intestinal ascariasis as intestinal obstruction, peritonitis, obstruction of the biliary and pancreatic ducts and liver abscess have other, and in some localities more common, causes; and, finally, the diarrhoea and dysentery which invariably result from heavy *Trichuris* infection display all of the features of amoebic and some other types of colitis.

In this connexion, special note must be taken of ascariasis. Because its complications are in nearly all instances secondary to other disease conditions (febrile, particularly) and complications may develop from light as well as from heavy infections, egg-count data indicating the relative worm burden have less significance than they have for *Trichuris* and hookworm infections.

LABORATORY DIAGNOSIS

For the three types of worm under consideration, specific diagnosis as applied to population samples is limited to the examination of faeces for the presence of eggs. Serological and intradermal tests are being developed, mainly for infections with tissue-invading stages, but none of them is ready for routine use (Sadun et al., 1957; Kagan et al., 1959; Jung & Pacheco, 1960).

Principles

The objectives in faecal examination are, of course, the detection and specific identification of all evidences of parasites. In addition to eggs and larvae, certain other objects, such as Charcot-Leyden crystals and cellular exudates, may provide presumptive evidence of helminthic infection. Occasionally the worm itself may be observed in the faeces but, in general, the success in detecting infection depends upon bringing the worm's reproductive product clearly into view, suitably magnified by the microscope. Culture techniques may be used for the hookworms (and for *Strongyloides*) (Sasa et al., 1958).

In endemic areas where new infections are being acquired more or less continually, a significant proportion of the infections cannot be detected by faecal examination because the worms are immature (pre-patent infections). The period of prepatency of each infection in relation to its average period of patency is often an important consideration with reference either to the most suitable time (season) for prevalence surveys or to the interpretation of prevalence data, or to both. *Ascaris*, for example, lives but a short time in the body, probably 8-12 months

on the average in people of different age-groups, and rarely lives more than 15 or 16 months; its prepatent period is about 2 months, i.e., one-fourth to one-sixth its parasitic life expectancy. As new infections tend not to be established in the intestine until after the previous one has been lost (Jung, 1954), survey data as an index of prevalence may be misleading if season of transmission is not taken into account. Theoretically, in areas where transmission is frequent and continuous throughout the year, patent (egg-producing) infections would not be found in all infected members of the population at any one time. Likewise, in an area where transmission is limited to one season of the year a survey would indicate high or low prevalence depending upon when it was carried out. As the periods of patency in relation to the periods of prepatency are relatively long for *Trichuris* (5-10 years or perhaps longer) and the hookworms (8-15 years), prevalence data are not greatly influenced by the season of sampling. On the other hand, prevalence data considered without reference to season of sampling are often misleading in relation to transmission among individuals of different age-groups.

Techniques

Many considerations must enter into the selection of the diagnostic technique most suitable for a given purpose. Therefore, the purpose of faecal examination and the kind of data required need to be clearly determined before a method of obtaining the data is chosen. The usual considerations in this connexion are: (1) the number of faecal samples to be examined within a given period; (2) the availability and cost of the required materials, facilities and personnel; (3) the kinds of infections to be detected, i.e., species of worms present in the population and the ones of chief interest; (4) the period of time that must necessarily elapse between the collection and the examination of the faecal samples; and (5) the kind of information to be derived from the data.

For survey purposes two general types of techniques—direct smear and concentration—may be used singly or in combination. The direct smear as generally used is a saline suspension of about 2 mg of fresh faeces prepared by stirring the faeces into a drop of saline on a slide, the suspension then being spread under a 22 × 22 mm cover-glass and examined under magnification of about 100 ×. Concentration techniques sort and concentrate the eggs (and other elements of similar density) either by sedimentation or by flotation. The direct smear can be used to obtain both qualitative and quantitative data, i.e., prevalence of infections and relative worm burden. Concentration techniques, on the other hand, are not suitable for obtaining quantitative data. In large surveys of outlying districts it is often desirable to preserve

faecal specimens in formalin (Ritchie, 1948; Ridley & Hawgood, 1956) or in a thiomersal-iodine-formalin mixture (Sapiro & Lawless, 1953) for later examination. Concentration techniques (by preservative-ether sedimentation) and the direct smear both can be used for getting qualitative data on preserved specimens; theoretically, the direct smear also could be used on preserved specimens for quantitative determination of relative worm burden, but thus far it has not been used for that purpose.

The most widely used and perhaps the most efficient concentration technique for the diagnosis of hookworm, *Trichuris* and *Ascaris* infections is brine flotation (saturated NaCl). If other parasites, including the intestinal protozoa, are to be included in the survey, zinc sulfate flotation on fresh specimens (Beaver, 1952a) or formalin-ether sedimentation (Ritchie, 1948; Ridley & Hawgood, 1956) is most commonly used. A method of concentrating eggs and protozoan cysts from thiomersal-iodine-formalin preserved faeces has been described (Blagg et al., 1955) but has not been widely accepted.

For the evaluation of *Ascaris*, *Trichuris*, hookworm, and some other less common infections, either in individual cases or in population groups, it is helpful to have an estimation of the worm burden in terms of very light, light, moderate, heavy and very heavy. In some instances three categories—light, moderate and heavy—would serve. It is not possible, except in cases of very light infections, to determine accurately the number of worms present. The most widely used method of making egg-counts is that described by Stoll & Hausheer (1926). This is a dilution method in which eggs are counted in a 0.075-ml sample of a 1 : 15 dilution of faeces, i.e., the sample in which eggs are counted contains about 5 mg (1/200 ml) of the original faecal sample. A newer method in which a somewhat smaller sample of faeces is used, and is referred to as the "standard faecal smear" method, was described by Beaver (1949, 1950). Although this method is relatively simple and may give more accurate estimates of worm burdens than does the dilution method, it has been tested by few workers (Melvin et al., 1956; Maldonado, 1956) and has not come into general use. Egg-counts made on ordinary direct faecal smears are sufficiently accurate for classification of light, moderate and heavy infections (Colbourne, 1950; Schuurmans-Stekhoven, 1953).

Training

In faecal examination, the efficient performance of technicians requires special knowledge of two general disciplines which are often insufficiently emphasized in training curricula. First, unless the tech-

nician has sufficient background in biology to give him a clear concept of what is meant by the term "species" and has an understanding of cellular organization, he will report false positives based on mistaken interpretation of artefacts and will be strongly inclined towards making identifications that are based on superficial resemblance of reference figures. This in turn leads to the placing of all parasite objects into one or another of the usual categories, thus leaving additional and unusual parasitic infections unrecognized and unrecorded. Secondly, the quantitative aspects of sampling and of diagnosing the worm infections cannot be overlooked in training programmes as doing so will lead to misinterpretations by both the technicians and those who use the laboratory reports. "Present or absent" interpretations will often be made without consideration of the adequacy of the sample and the reliability of the statistics. Other aspects of training such as recruitment and qualifications need no special comment.

ANTHELMINTIC TREATMENT

Choice of drug

There is no single drug or combination of drugs that can be depended upon to expel all kinds or even all of the more common kinds of worms. Dithiazanine, which Swartzwelder & Frye (1957) have called a "broad spectrum" anthelmintic, is unquestionably the most effective orally administered drug available for use against *Trichuris trichiura* and *Strongyloides stercoralis*. It is effective against *Ascaris lumbricoides* and *Enterobius vermicularis* but is less so and more toxic than the piperazine compounds. Dithiazanine is said to be somewhat effective against *Necator americanus* but the results reported thus far are not conclusive.

The only drug which approaches the ideal (safe, efficient, easily administered and inexpensive) is piperazine, and it is useful for only *Ascaris* and pinworms. As mentioned above, the best drug for *Trichuris* and *Strongyloides*, indeed the only effective one that can be given by mouth, is dithiazanine. However, it is in no respect ideal. For the hookworms two drugs—tetrachloroethylene and bephenium—are at present in competition for first place. Neither is ideal with respect to efficiency. Single administration of either generally expels a high percentage of the worms but to eradicate completely an infection may require several treatments. Bephenium is possibly more effective for *Ancylostoma duodenale*, whereas tetrachloroethylene is nearer the ideal for *Necator americanus* (Foy & Kondi, 1960). This needs further study, however. The matter of relative toxicity of these two drugs needs

further study also (Jung & McCroan, 1960). However, neither is suitable for a hookworm eradication programme.

Mass treatment for the control of ascariasis

While the use of anthelmintics in attempts to eradicate the soil-transmitted intestinal helminths as a group must await the development of more ideal drugs for *Trichuris* and hookworms, it apparently would be feasible to begin such a programme against *Ascaris*, at least in selected areas. A recent field trial using piperazine in periodic mass treatments in an isolated village in Mexico produced impressive results (Biagi & Rodriguez, 1960). All members (or essentially all) of the population were given single doses at intervals somewhat shorter than the prepatent period of the worm, and the dosing was continued until there was no longer evidence of new infections being acquired from the store of infective eggs originally present in the soil. Since piperazine is highly effective (removing almost all young and old *Ascaris* from the intestine), is not toxic and can be made pleasant to taste, is readily available in large quantities, and is relatively inexpensive, and considering that ascariasis is both damaging to health and extremely difficult to control by other means, mass treatment programmes in areas where the *Ascaris* problem is particularly pressing could now be undertaken with the expectation of yielding significant benefits.

In addition to the demonstrated desirability and feasibility of such a programme, the essential conditions to be considered in the planning of periodic mass treatments for the control of ascariasis are: season(s) of transmission, period of prepatency, development and persistence of infective eggs in the soil and sources of reinfection.

Season of transmission. In areas where new infections are acquired with more or less equal frequency throughout the year, the first of a series of periodic treatments could be given at any convenient time. Where there are seasonal variations in temperature and rainfall, there are corresponding periods of maximum and minimum acquisition of infection and there is one period of the year during which infection rates and worm burdens are highest. To obtain the greatest remedial benefit to the people and to elicit the greatest popular interest in the treatment programme, the first treatments should be given when the maximum number of worms will be expelled from and observed by the people. In tropical areas this period would be two to three months after the onset of the rainy season if the dry season is short, and four to five months after the first week of rain if the dry season is long and severe, i.e., more than two months without rain.

Period of prepatency. The time required for a new infection to reach the egg-laying stage is about 60 days. As the interval between treatments must be sufficiently short to disallow egg-laying by worms acquired immediately after the previous treatment, the interval between mass treatments must not exceed two months and ideally would be somewhat shorter, but not less than 30 days.

Soil infectivity. Under ideal environmental conditions eggs become infective in about two weeks. They are destroyed by direct sunlight, high temperatures and desiccation. The rate of development and persistence of infective eggs in the soil will depend upon the combined effects of these individual conditions, and these in turn depend upon the climate and the quality of the soil. In open sandy soils eggs develop poorly and are soon destroyed; in dense colloidal soils they rapidly become infective and are preserved near the surface for many weeks or even several months; they may possibly remain infective for more than a year, but it is improbable that they would persist that long in any situation where they would be readily ingested. Periodic mass treatments would have to be continued as long as infective eggs remain in the soil, and in areas where endemicity is high the minimum period would be six months or longer. This could be determined most easily by examining post-treatment stools for worms (not eggs) and continuing the treatments for one interval beyond the apparent failure of the worm to establish new infections.

Sources of reinfection. While a single treatment might fail to remove all worms in individual cases, after the treatments had been repeated a number of times no worms should remain among persons present at the beginning of the programme. If all individuals of the population are included in the mass treatments there would be only two possibly important sources of reinfection. Infected individuals entering the area after completion of the programme could, of course, readily re-establish endemicity. This could be avoided in some instances by regulation of immigration. Another possible source of reinfection is the pig. *Ascaris* of pigs apparently is a distinct race that does not readily mature in humans but to be on the safe side pigs should either be excluded from the area or included in the mass treatments. Experimentally the pig *Ascaris* has produced patent infections in human volunteers (Takata, 1951). However, in one apparently successful trial of mass treatment, pigs were ignored (Biagi & Rodriguez, 1960).

Evaluation of drugs

Scores of new anthelmintics have been offered and tested within recent years. An observation which invites analysis is that as each new

drug is offered the first trials are reported with enthusiastic predictions of usefulness, later trials cast doubts, and finally it becomes evident that the new drug is faulty in one way or another and it is soon forgotten. To some extent this pattern is due to natural bias in favour of anything new; chiefly, it derives from failure to constitute properly a team of investigators. Evaluation of anthelmintics involves the parasite and the patient as well as the drug. It therefore requires competence with regard to the worm and to the patient simultaneously and it requires some degree of competence in statistical analysis. These requirements are seldom met without the participation of a doctor, whose concern is with the patient, and a parasitologist, whose concern is with the parasite. It is not enough to have a doctor who merely observes and certifies that no apparent harm was done the patient, or a "parasitologist" who is the doctor's technician and serves merely as witness to the "significant reduction in egg-counts".

The highest degree of fault is generally to be found either in the failure to detect and clearly report toxicity, or in the manner of making and interpreting egg-counts. Concerning the latter, it should be noted that there is often too great and unnecessary reliance on egg-counts. The collection and enumeration of expelled worms is an unpleasant task and sometimes is difficult to arrange; yet it provides the most satisfying kind of evidence of anthelmintic effect (Foy & Kondi, 1960). Egg-counts are most often misused because of failure to take into account the depression of egg output by worms remaining in the bowel or the fact that egg-counts are estimates rather than measurements; at times the technique of making egg-counts is faulty.

CONTROL METHODS

CONSIDERATION OF OBJECTIVES

In any area where endemicity is high and enduring, eradication of either hookworm or *Trichuris* infection would at present be an unrealistic aim. Nearly complete control of ascariasis could possibly be attained in somewhat isolated areas, though it would require considerable effort and expense. With the available techniques and materials fairly large populations, if placed under strict discipline, could be made free of all intestinal parasites. In view of the difficulties of accomplishment and the certain necessity of continuous efforts to prevent re-establishment of endemicity, it is hard to conceive of a situation in which such a programme could be justified. In the fight against parasitic diseases in China the achievements have not been great as regards the soil-transmitted worms (Hou et al., 1959). The example of the disappointing anti-hookworm campaigns of the Rockefeller Sanitary Commission and International Health Board should dampen any enthusiasm which might arise from a consideration of theoretical possibilities. On the other hand, it is worth while to consider some of the improvements that have been made in control techniques over the past thirty years and to examine newer knowledge which may be useful in attacking the worm problem.

APPROACHES TO CONTROL

Control of intestinal helminthiases may be viewed as a step-wise operation which begins with populations whose major health problems are related to such basic needs as food, housing and sanitation, and ends when these needs are so nearly satisfied that transmission of infection meets natural barriers. As the basic needs of the individual and community are provided, both the transmission and the effects of worm infections diminish and eventually lose public health significance. In the transition stages, however, if climate and soil conditions are highly

favourable to transmission, the problem of intestinal helminths will be an enduring one and may at times be aggravated by social and economic maladjustments. A control programme, therefore, should aim at developing natural barriers to transmission and abating the retarding effects of disease, not the eradication of the infections. Programmes thus far have emphasized sanitation, treatment and shoes. These measures may have had some other values but they have had little lasting effect on the prevalence of soil-transmitted helminths.

Sanitation

In communities where living standards are at or near subsistence levels the installation of latrines or other crude devices for faecal disposal fails to attain its goal of barring contamination of the soil. Observation of such communities readily reveals the chief obstructions to success. Latrines of durable quality are costly to install and costly to maintain; they are frequently inconveniently located and repelling; rarely are they comfortable or in any respect inviting; and in some instances they are themselves a source of contamination of the immediate environment. Of greater importance is the fact that they do not in any case reduce contamination by toddler-age children (1-3 years) whose promiscuous defecation is essentially uncontrollable and is universally countenanced. Even in communities where most of the families have reached flush-toilet status, ascariasis and trichuriasis may remain endemic as a result of sibling to younger sibling transmission through the soil in the immediate vicinity of the houses. To a much greater extent than is generally realized, hookworm infection is likewise transmitted in this manner. Promiscuous defecation by agricultural workers is apparently of minor importance except under unusual circumstances.

Disinfection

Soil. Chemical soil disinfectants recommended for use in kennels and poultry farms could possibly be used to a limited extent around human habitations. It is doubtful, however, that they would be suitable for disinfecting larger areas of contaminated soil. Drainage and breaking up the surface of the soil to hasten desiccation of infective eggs and larvae, and turning the soil to put infective eggs deep below the surface have been recommended, but these measures would be neither reliable nor practical for general use.

Faeces. Fertilization of soil with human faeces either as night-soil or as irrigation sewage poses special problems. Although a very high

proportion of the viable eggs that reach the soil in this manner fail to develop, and most of those that become infective are destroyed by direct sunlight or desiccation, there are some that survive and return to the cities, villages and homes on food-plants that are consumed raw or pickled. *Ascaris* and *Trichuris* eggs and hookworm larvae have been demonstrated on vegetables at markets supplied from sewage-irrigated or night-soil-fertilized farms. Proper storage of night-soil and methods of composting can be relied upon to kill even the most resistant helminth eggs but such methods are said to be unpractical for many situations and in any case rigid regulation and supervision are required if they are to be effective.

Uncooked vegetables. Certain fruits and vegetables are much preferred in the raw state. Where fuel is scarce or expensive a high proportion of vegetable foods are of necessity eaten uncooked, either fresh or pickled. Older methods of disinfection, such as scalding and peeling, are not always satisfactory and are to some extent unreliable as a safeguard against any of the common infections acquired from fresh foods. Potassium permanganate has no effect on helminth eggs. Full-strength vinegar is quickly lethal to amoebic cysts, other enteric organisms and hookworm larvae but is harmless to infective eggs of *Ascaris* (Beaver & Deschamps, 1949; Soh, 1960). Most of the other commonly used food preservatives, such as brine, syrup and natural acids, oils, and spices, have little or no effect on infective *Ascaris* eggs. However, Soh (1960) has shown that garlic and mustard oils are highly toxic to the infective stages of *Ascaris* and hookworms.

The only known chemical disinfectant that may be practical for disinfection of fresh fruits and vegetables is aqueous iodine such as is used for sterilizing dairy and restaurant equipment. In a recent study by Prayuth (1961) it was shown that solutions of sufficient strength (200 p.p.m.) to kill promptly (10 minutes) infective eggs and larvae of *Ascaris*, *Trichuris*, hookworm and *Strongyloides* do not affect the appearance or flavour of common types of rooty and leafy vegetables. As it is also lethal to all known types of enteric organisms, aqueous iodine would appear to be useful in a wide range of situations.

Treatment

As already pointed out, treatment as a means of interrupting transmission offers no promise of significant success except with ascariasis, because the drugs available for ankylostomiasis and trichuriasis usually expel some but not all of the worms. Moreover, light infections with any of the intestinal nematodes are well tolerated and it is difficult to

persuade healthy carriers to submit to repeated unpleasant treatment. The soil-transmitted worms produce enormous numbers of eggs. The average stool from an individual harbouring a single pair of worms of each species might contain 200 000 *Ascaris* eggs, 50 000 hookworm eggs and an equal number of *Trichuris* eggs. Under favourable conditions of climate, soil quality, coprophagous beetle activity, and protection from direct sunlight a high percentage of eggs reaching the soil become infective. It has been shown that a damp cotton pad about 16 cm in diameter may pick up nearly 25 000 hookworm larvae in a few minutes from a spot where faeces containing only 50 000 eggs were deposited six days earlier (Beaver, 1953). As hookworms live in the intestine up to 15 years (Palmer, 1955), *Trichuris* perhaps 10 years, and *Ascaris* up to more than a year, and as their infective stages persist in soil for several weeks (hookworm) or months (*Ascaris* and *Trichuris*), it is evident that unless all worms are removed repeatedly from the entire population over relatively long periods, treatment alone will not succeed in interrupting transmission.

Shoes

Insistence upon wearing shoes as a protective measure against hookworm infection is unrealistic. Shoes of such quality as would provide protection are beyond the means of those who need them for that purpose. There is essentially no hookworm transmission except in wet situations and expensive shoes are almost certain to be removed to avoid damage to the shoes and the discomfort of wet feet in them. The barefoot habit has such firm practical basis and is so strongly preferred in all situations which favour hookworm transmission that it is unrealistic and to some extent cruel (to children at least) to urge the purchase and habitual use of shoes.

Ecological approach

Except to discourage faecal contamination of the soil, control programmes have not attempted to deal with the environmental factors of transmission. In view of the failure of conventional measures and the rather precise conditions known to be required for incubation and preservation of infective stages in the soil, and thus the vulnerability of these stages to destructive slight environmental alterations, it would seem that the most promising approach to the control of transmission may be through the application of ecological principles.

The spotty, discontinuous distribution of infections within broad endemic areas, where the climate and the habits of the people are essen-

tially uniform, indicates in a general way that *Ascaris*, *Trichuris*, hookworms and other soil-transmitted species can succeed only where environmental conditions in the soil are favourable. Numerous studies have shown that soil texture or constituents must provide an open, light type of soil for hookworms, whereas *Ascaris* and *Trichuris* demand heavy, colloidal soils. The requirements of each species are much more exact than this, however. Observations on the peculiarities of distribution of these worms in Egypt (Scott, 1939), Northern Rhodesia (Buckley, 1946; McCullough & Friis-Hansen—unpublished data, 1959) and Georgia (Beaver, 1952b) show that the essential environmental factors are numerous and complex and that some are still unknown. The particular condition or conditions which through their presence or absence bar transmission in certain localities have thus far escaped detection. In some instances the scarcity of infection may be due to “a summation of minor factors, each of which is unrecognisable when acting alone” (Scott, 1939).

The individual requirements of each species in each of its developmental stages have been extensively studied and many of them are rather precisely known. The tolerance ranges and optimal levels have been determined with reference to light, moisture, temperature and oxygen, and the physical types of soil (sandy, loam, clayey) which most adequately supply these requirements are known at least in a general way. It is therefore possible to recognize environmental conditions which are favourable for transmission and to define conditions which are not.

Before discussing the possible application of ecological principles to actual control operations, it should be mentioned again that in almost all highly endemic areas, including to a large extent those in which night-soil is used, the greater part of transmission occurs in the immediate vicinity of the family home. The family is the essential population unit, and the two combined constitute the ecological unit. Aggregations of families in villages, compounds, towns, etc., extend and intensify transmission, but the same basic ecological principles apply to situations encompassing aggregations of various numbers of people and families.

RECOMMENDATIONS

DISEASE CONTROL

In most types of long-established communities, particularly those in which the use of open defecation sites is a fixed pattern, attempts to control transmission may not be feasible by any means. The best that can be done in assisting such communities is to direct control efforts towards the diseases rather than the infection and its transmission. In such areas where endemicity cannot be attacked, morbidity and mortality can sometimes be controlled or significantly reduced by periodic screening and by treating the most heavily infected individuals. The patterns which such remedial programmes should follow would necessarily vary in different communities with different types of habits, conditions and resources, and with different disease problems. Usually it would be a matter of selecting diseased individuals in the most feasible (least costly) manner and treating them with the most satisfactory anthelmintics and supplementary drugs (iron), both phases being incorporated into general health services and co-ordinated with other programmes of community improvement. Perhaps one of the most difficult decisions in this connexion is which, if any, of the soil-transmitted helminths are contributing significantly to the health problems of the community. Since the relationships between prevalence of infection and significance of disease cannot be determined by formulae and must in all cases be determined separately for individual communities which often differ markedly within political boundaries, the question of the relative importance of worm infections as a disease problem may require expert examination. Much time and money may be wasted on the control of ankylostomiasis in regions where hookworm disease is a minor problem.

TRANSMISSION CONTROL

Undertaking futile programmes to eradicate infection or making useless attempts to control disease can be more readily condoned than

can failures to grasp promising opportunities to prevent disease transmission. It has been emphasized that interference with either human or parasite ecological relations in long-established communities is difficult and costly. Even greater emphasis might be placed on the probable ease with which environmental conditions in newly established communities could be made untenable for parasites and thus more ideal for the re-located inhabitants. The extent to which this has been done or has been considered in the planning of future programmes has not been determined. It has been observed, however, that whether planned with that objective in mind or not, new low-rental housing projects in New Orleans, La., have essentially eliminated the problems of ascariasis and trichuriasis among the families now re-located there from previous slum areas. Two features which bar transmission of soil-transmitted helminths are evident in the construction plan: (1) the units have been so arranged that promiscuous defecation, disapproved by the community members generally, cannot occur unobserved; and (2) in all outside areas where children are permitted the surface has been made unsuitable for incubation of infective stages of helminths. There are, of course, in addition flush toilets conveniently available to all families, but these facilities do not eliminate all faecal contamination of outside areas by the younger children.

Features serving as barriers to transmission of soil-transmitted helminths could almost certainly be included in the construction of new ("model") villages for displaced or re-located families. The particular form they would need to take would be determined by a number of considerations—topography, type of base soil, climate, culture, availability and cost of materials, and magnitude of the project. To a limited extent, environmental "conditioning" to interfere with soil transmission of infections could be a part of improvement programmes for old communities.

CONCERNING MISCELLANEOUS HELMINTHS

STRONGYLOIDES STERCORALIS

Strongyloides stercoralis is generally regarded as a soil-transmitted helminth having much the same epidemiology as the hookworms. The extent to which this is true is essentially unknown. No detailed epidemiological studies have been carried out on strongyloidiasis for the apparent reason that it is not a recognized health problem in any large area of the world. The infection is especially prevalent in Panama, the Indochinese peninsula and southern Louisiana in the USA. When it is common it is frequently associated with disease, and deaths have been attributed to it. Its pathogenicity has stimulated numerous investigations of the life-cycle but these studies have been largely descriptive. There is so little known about the factors which determine its behaviour, either in or outside the body, that this worm is often said to be the most *unpredictable* human parasite.

There is no immediate need for control programmes directed particularly against strongyloidiasis. If there were, the only special recommendation to be made would be that "the situation should be studied". Programmes of control that were successful against the soil-transmitted species might affect *Strongyloides* also, but not necessarily so. Although there is obvious similarity between it and the hookworms, there are important differences. Their distributions are often sharply different. In the most highly endemic area of strongyloidiasis in the United States of America (south-eastern Louisiana) hookworm transmission does not occur; in an adjacent region where hookworm is highly endemic, *Strongyloides* is uncommon. Other important differences are that *Strongyloides* readily reaches the infective stage in the faecal mass, whereas hookworm almost never does so, and that the exogenous stages of *Strongyloides* develop readily in aquatic situations in which hookworm stages would drown. It is therefore understandable that *Strongyloides* is most highly endemic in regions where the temperatures are high and the water-table is near the surface.

The drug of choice for this infection is, at the moment, dithiazanine. If given in course and repeated once or twice after a rest-period of seven to ten days, it generally terminates the infection. Patients may find this drug troublesome but they usually can tolerate the full course.

No special techniques of stool examination have been developed for *Strongyloides*. Combination of direct smear and concentration techniques or the Harada-Mori test-tube culture are satisfactory for diagnosis in surveys (Sasa et al., 1958). Modification of the Bearmann technique recommended by some workers is cumbersome (Gomes de Moraes, 1948).

HYMENOLEPIS NANA

Hymenolepis nana is one of the most common helminths found in the people of arid regions. It may possibly be of public health importance for certain groups of people but it has not been reported as such. If attempts were to be made to control this infection it would be necessary to determine the epidemiological aspects of transmission. Its association with arid regions has not been adequately explained. The infection resembles strongyloidiasis in that it is unpredictable as to internal auto-infection and pathogenicity. Quinacrine is probably as effective as any of the drugs in use; infections are not easily terminated. Spontaneous loss of infection is apparently common, especially in adults.

LIVER FLUKES

Liver fluke infection is a cause of considerable morbidity and mortality in local areas of much of the Far East. Neither *Clonorchis* nor *Opisthorchis* transmission can be easily attacked but, as curative measure are unsatisfactory, consideration should be given to the improvement of preventive measures. Present knowledge is inadequate for serious attempts at curbing transmission except on a limited scale and under special circumstances.

LUNG FLUKES

Lung fluke disease is of sufficient frequency to have public health significance in certain localities of Korea, mainland China, Taiwan and the Philippines. The most highly endemic area yet defined is apparently the one in South Korea. Recent studies there, summarized by Sadun & Buck (1960), indicate that in small foci the infection may occur in more than 50% of the people. Whether reservoir hosts have

any significant role in maintaining endemicity has not been carefully examined. Also, whether the *Paragonimus* found in humans is exclusively *P. westermani* has not been determined. In relation to control possibilities, both of these questions are basic. In such well-circumscribed areas it should be feasible to interrupt transmission completely if man is the only final host and the intermediate hosts (snails and crustaceans) are correctly identified. Published information indicates that one or two localities in South Korea would be ideal for a study of feasibility of control.

ZOONOTIC HELMINTHIASES

In most parts of the world people live in rather close association with one or more species of domesticated mammals. The horse, ass, cow, camel, buffalo, sheep, goat, pig, dog, cat, rat and monkey all harbour helminths which are especially adapted to them. Some of these parasites are transmissible to man. In the human host, the worms from other animals may or may not develop to maturity and produce eggs, that is, the infection may or may not become "patent" and detectable by faecal examination in the same manner as those which naturally occur in man. For some species, such as *Trichostrongylus* spp., man may serve to maintain a certain degree of endemicity with little or no assistance from the natural hosts. In most instances, however, man is merely an incidental host.

Knowledge of the zoonotic infections which regularly become patent, though incomplete in many details, is adequate for general appraisal of their relative importance as public health problems. Concerning those which do not become patent our knowledge is very sketchy. In recent years, however, it has been amply demonstrated that in certain localities cryptic infections acquired from dogs, cats and rats rank high among the causes of disease and death, and in highly developed areas they may rank higher than all other parasitic infections. It has been pointed out earlier that the relative abundance of soil-transmitted human parasites in a community is a fairly accurate index of its socio-economic status. The observation has also been made that as the higher levels of community development are attained and the usual types of parasite disappear, the unusual (cryptic) types which were earlier not detectable among the common types become increasingly evident. In the areas with better sanitation, where human faeces are rarely permitted to contaminate the soil, the only remaining important source of contamination is that provided by domestic animals. Thus the zoonotic infections naturally become the only ones of public health importance (Beaver, 1959).

Most extensively studied among the cryptic helminthiasis is toxocariasis, acquired by ingestion of soil earlier contaminated with faeces of dogs. Awareness of this infection has stimulated curiosity about the possible contribution of other intestinal nematodes of animals to the health status of people who obviously ingest a great variety and abundance of infective stages of animals' parasites. Conceivably, certain parasites may be responsible for diseases attributed to other causes or classified as "of unknown etiology" (tropical eosinophilia); others may indirectly contribute more to health than to disease by stimulating sufficient non-specific immunity to bar the acquisition of damaging infections or to increase the tolerance of infections that would otherwise be damaging. Mention of the latter possibility—i.e., the positive value of cryptic zoonotic infections—is of course conjectural. It comes to mind as a possible factor, among others, which creates such epidemiological puzzles as those seen in Northern Rhodesia, where ascariasis and trichuriasis are unaccountably scarce, or in West Pakistan, where ankylostomiasis is extremely prevalent but the worm burdens are unaccountably low. An example of the opposite situation is seen in Durban, Union of South Africa, where amoebic colitis is unaccountably severe, possibly as a result of concomitant cryptic helminthiasis. These questions suggest research problems which either have not been investigated at all or have not been solved because they have been too narrowly perceived.

RESEARCH PROBLEMS

In the discussion of the control of soil-transmitted intestinal nematodes, two general aspects were stressed—remedial measures based on accurate detection and successful treatment of *disease*, and effective interruption of transmission of *infection* by means of environmental conditioning which would simultaneously be advantageous to the people and disadvantageous to the parasites.

REMEDIAL ASPECTS

To sort out and treat the diseases produced by parasites new information is needed on the following.

Factors which produce high prevalence of light infections

It is obvious that the parasite burden in most of the individuals in areas of extremely high prevalence does not represent the total inoculum. Exposure to infection is presumably frequent and heavy. If light infections are due to humoral immunity or to premunition or to crowding interference, what are the abnormal conditions which permit the establishment of heavy infections?

Disease in relation to light infections

The particular conditions, if any, under which a few hookworms or ascarids can produce disease is a matter of considerable interest. Although there is no known basis for their doing so in well-nourished individuals, there are reports of anaemia being produced by hookworm burdens which ordinarily have no detectable effect. *Ascaris* in small numbers are said to have toxic or allergic effects in certain individuals; the latter has an understandable basis, the former does not.

Nutrition and host resistance

Nothing has been done with *Trichuris* in this regard. Some reports indicate that malnutrition favours the establishment and development of *Ascaris* and hookworms; others indicate the opposite. The duration of heavy hookworm infections in either poorly or well-nourished individuals has not been adequately studied. "Crisis" and "self-cure" seen in dogs and other animals with heavy hookworm burdens may or may not occur in humans. The hookworms of man are very different from those of dogs; observations made on the hookworms of dogs therefore cannot be applied to those of man.

Improvement of anthelmintics

Better anthelmintics are needed for hookworms and *Trichuris*. The best ones available are either toxic or relatively inefficient, or both.

Survey methods

Methods of making reliable selective surveys need to be reviewed and tested. Perhaps new techniques can be developed. The reliability of direct smear counts needs to be tested further. Thus far comparisons have been made between direct smear and dilution counts, showing that in general they agree in the variability of estimates. They have not been compared adequately with respect to variability from day to day, i.e., the reliability of daily counts on a single individual has not been tested. The feasibility of using direct smear counts instead of "standard" smear counts needs further testing. Further testing is perhaps not necessary to prove the fact, but it is needed to popularize the method.

INTERRUPTION OF TRANSMISSION

Available facts encourage the view that environmental management to the disadvantage of soil-transmitted helminths is a feasible approach to control. To provide greater choice of methods and to encourage greater interest in the use of that approach, the following studies would possibly be helpful.

Location of infective sites

The relative amount of transmission that occurs through the soil around the dwelling as compared with other locations is in general

evident in the age/sex prevalence statistics, but actual soil studies in situations where such transmission is doubted are needed to provide a firm basis for conclusions.

Unexplained low endemicity

Identification and evaluation of natural adverse conditions should be attempted in areas where worm infections apparently should, but do not, occur. A good example of this situation is the Fort Rosebery area of Northern Rhodesia where *Ascaris* and *Trichuris* are essentially lacking among people who have moderate to high rates of hookworm infections and could easily acquire "inoculations" from neighbouring districts where *Ascaris* rates are extremely high. *Trichuris* is present but occurs only rarely in any of the communities of the region. Until the absence as well as the presence of infections can be fully explained, it must be assumed that important control possibilities are being overlooked. Investigations of this problem, carried out by workers who have thorough understanding of the soil, ecology and worms, would doubtless be fruitful. In this connexion, the positive and negative influences of coprophagous insects with reference to different species of worms should not be overlooked.

Alteration of soil

Conditioning of the soil by means of adding materials and chemicals to change its physical properties should be investigated from the standpoints of control values and feasibility. This is a "high priority" problem in connexion with construction of new housing and model villages. For heavily contaminated soil in old villages and other long-established situations, the possibility of using chemical disinfection, residual or otherwise, should also be investigated. Substances used on kennels (calcium cyanamide, sodium borates) and poultry farms (pentachlorophenate) might prove to be useful.

Population re-location

With knowledge already available, natural control methods should be applied and evaluated as a part of any experimentation with population re-location and village construction.

Night-soil and sewage irrigation

Night-soil fertilization poses four problems which could profitably be studied.

Disinfection methods. How best to disinfect the night-soil by composting or other forms of heat sterilization and by storage with and without the addition of substances to accelerate killing of eggs and organisms. There is special need for methods adaptable to small farm units.

Natural decontamination. There is need for an objective evaluation of the relative importance of night-soil fertilization as compared with other factors in transmission. Contamination in the immediate vicinity of the dwelling, direct (by young children) and by handling of night-soil, is possibly accountable for most of the infection attributed to field contamination of vegetables.

Crop relations. It would be interesting and possibly helpful to investigate the validity of the view that raising certain crops (such as coffee, sugar cane, rice) encourages direct contamination of soil and infection transmission. It may only be that the soils are especially suitable for the worms as well as the crop, and that the people employed in the cultivation of such crops are especially prone to contaminate the soil at their own doorsteps and are particularly susceptible to disease from worm infections (because of malnutrition?).

Food disinfection. Disinfection of uncooked fruits and vegetables by use of aqueous iodine appears to be feasible under certain circumstances. Field trials at military or civilian establishments in areas where night-soil is commonly used would be highly worth while.

DIAGNOSTIC METHODS

While concentration techniques undoubtedly detect some very light infections that would be missed if only direct smears were used, there is a general tendency to over-emphasize that feature, to place undue confidence in the results from concentration techniques, and to employ complicated, expensive procedures unnecessarily. There is no all-purpose technique, one that is entirely reliable in detecting all kinds of parasites. Each of the standard concentration techniques has been developed for detecting particular infections or groups of infections, and to a large extent the evaluations of them have been made without reference to the special qualities of different types of stools. While faeces uniformly contain certain basic elements, there is a tremendous variation in the types and amounts of residues from diets that are more or less peculiar to people of different regions. These elements greatly influence the relative efficiency of different techniques of examination.

The enthusiasm for concentration techniques has tended to depreciate the direct smear, to discourage its use in some cases and to encourage improper use of it in others. The latter is especially evident when reported data are examined with reference to the output of eggs by *Ascaris lumbricoides* and *Necator americanus*. It has been shown that direct smears, prepared by experienced technicians for the diagnosis of the usual types of parasites, contain the equivalent of about 2 mg of formed faeces, distributed more or less uniformly under a 22 × 22 mm cover-glass. It has also been shown that eggs contributed to the bowel stream above the levels where fluid bowel contents are reduced to colloidal faeces are randomly distributed in the faecal mass (Beaver, 1949). Therefore, if eggs are present in numbers equal to or exceeding 2000 per gram (2 per mg), complete examination of a 2-mg sample should detect almost all cases. A single *Ascaris* female, inseminated or not, produces 200 000 eggs or more per day. Since the average formed stool is about 100 mg, a one-female infection should on the average put at least two eggs per mg in the (formed) faeces. Therefore, *Ascaris* infections should

be rarely found by any other method if they are not detectable by direct smear. Nevertheless, trials in which the diagnostic efficiency of concentration techniques has been compared with that of the direct smear have usually shown a high percentage of failures for the direct smear. This, of course, indicates improper preparation or careless examination of the smear. The misuse of the direct smear is similarly evident in hookworm data. It is known that one inseminated *Necator* produces at least 200-500 eggs per gram of formed faeces (Beaver, 1955). Since, therefore, the probability of finding a high proportion of infected individuals with egg-outputs below the threshold of the direct smear is very slight, results from comparative tests which greatly favour a concentration technique for diagnosing hookworm infection suggest inefficient use of the direct smear. It was observed years ago, before concentration techniques came into general use, that experienced technicians did not fail to find hookworm eggs by direct smear if stools contained a minimum of 300-500 per gram (Hausheer & Herrick, 1926).

Of the two general types of egg-counting techniques—dilution and standard smear—the small-drop modification of the Stoll dilution procedure described by Stoll & Hausheer (1926) is the more generally used. The chief advantage claimed for it over the standard direct smear is that it employs a 4-g sample of the faeces whereas the direct smear technique employs only a few milligrams. If it is accepted that eggs entering the bowel stream at levels above the faeces-forming segment of the colon are randomly distributed in the faeces, the large (4-g) sample used in the dilution technique cannot be regarded as representing a more reliable sample. Actually, the sample sizes are essentially the same. The direct smear sample that is generally used contains 1/500 g equivalent of formed faeces. The dilution sample in which eggs are counted is 1/200 g (0.075 ml of a 1:15 dilution) of faeces but the counts must then be corrected for stool consistency by multiplying the actual count by factors of 1.0, 1.5, 2.0, 3.0 or 4.0 respectively for stools of formed, mushy-formed, mushy, mushy-diarrhoeic and diarrhoeic consistency. As soft faeces can be handled most easily (when measuring by displacement), if given any choice the technician usually takes samples requiring correction for consistency. Thus from mushy stools the final sample is 1/400 g and from softer specimens it is 1/600 g; the average may be close to 1/500 g, the same as that used in the 2-mg direct smear. Two independent evaluations of these techniques (Maldonado, 1956; Melvin et al., 1956) have shown no advantage in one over the other so far as sample size is concerned.

As described originally the standard smear technique is not suitable for routine use in the type of diagnostic laboratory usually seen in the hospitals and clinics in under-developed countries. The precise measure-

ment of smear density with a photometer is unpractical in those circumstances, since electricity is often not available for microscopic work, the apparatus is easily damaged and recalibration of the photometer is perhaps too involved for the average technician. However, the standard smear does have usefulness in the training of technicians and can be used to great advantage where it is desirable to have egg-counts as reliable as possible.

Concerning the reliability of egg-counts, it should be mentioned that workers in general tend to overlook the statistical character of egg-counts as estimates of egg output and worm burden. The number of eggs counted in a microsample of faeces is a highly variable figure regardless of the accuracy with which the sample is measured and the eggs are counted. A single count of 15 eggs in a given sample may be at either extreme of the expected range in counts obtained from multiple sampling of the same universe (faecal mass), and for higher counts the expected range is somewhere in the neighbourhood of the square root of the mean on either side of the mean. Thus a single count of 16 may represent a mean count anywhere between 12 and 20, and if the mean is 12 the expected range would extend to around 9 at the bottom and to around 24 at the top of the range, i.e., a count of 16 merely places the true mean somewhere between 9 and 24 eggs per sample of that magnitude. Two, three or more counts would of course narrow the estimate of probable range, and for some purposes, such as evaluating results from small series of treatments, multiple counts to obtain fairly reliable mean counts are essential. Doing one count before treatment and one after treatment has little value. On the other hand, a single count does give absolute reliability within the limits outlined above. A count of 16 indicates, for example, that the true mean cannot possibly be less than 5 or greater than 30 if repeated on the same stool or on the same individual on successive days.

Applications of egg-count data to practical problems fortunately may often require only roughly determined egg-output. In surveys to determine the extent and intensity of *Ascaris*, *Trichuris* and hookworm infections, reliable determination of the relative number of clinically important infections is all that is needed and, regardless of the accuracy of the individual counts, they will in the end be grouped into only a few, very inclusive categories such as "light", "moderate" and "heavy", or perhaps five categories, adding "very light" and "very heavy". Since counts near the cut-off points fall equally on either side of these points, errors in classification are self-correcting when large numbers are dealt with.

In view of the above observations it is evident that for many purposes the egg-counts need not be highly accurate from the standpoint

of reliability within a narrow range. Individual worms produce eggs in very great numbers and the egg-output from relatively small, moderate and large numbers of worms differs greatly. Even brief experience in counting eggs in direct smears leads to natural grouping into "few", "many" and "intermediate" classes for each species of worm. As already noted, experienced technicians tend to make uniform smears containing the equivalent of about 2 mg of formed faeces. The uniformity of smears at that density results from the early realization that small eggs and cysts are not readily visible in heavier smears and there is an obvious loss of efficiency in the use of lighter smears, (prepared in one drop of saline and mounted under a 22 × 22 mm cover-glass). It has been found that the egg-count in terms of eggs per smear is entirely satisfactory for clinical purposes at the Charity Hospital in New Orleans and at least one worker has used the "eggs per smear" unit in describing the result from extensive helminth surveys (Schuurmans-Stekhoven, 1953). The fact that there is generally more interest in the relative worm burden than in the mere presence of a worm infection provides strong support for egg-counting as a routine procedure. The fact that it requires no special equipment not included among basic items for any diagnostic laboratory and requires very little additional time over that required for ordinary qualitative diagnosis, and in addition, tends to impose the desirable discipline of complete examination of the smear, provides strong support for the direct smear as a technique for obtaining egg-counts.

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