EVALUATING MEASURES TO CONTROL INTESTINAL PARASITIC INFECTIONS

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Introduction

Current estimates suggest that at least one-quarter of the world's population is chronically infected with intestinal parasites and that most of these infected people live in developing countries (1). Because of the scale of this public health problem and the limited economic and technical resources available, it is essential that control programmes be carefully designed and evaluated. The design of procedures to evaluate control measures requires a clear understanding of the epidemiological characteristics of the infection to be controlled, and an appreciation of the epidemiological differences between helminths, protozoa and other infectious agents.

For epidemiological purposes it has been suggested that all infectious agents can be separated into two groups: macroparasites, a group which comprises the helminths, and microparasites, a taxonomically diverse group including viruses, bacteria and protozoa. The characteristic which requires this separation is the biology of helminth reproduction: while most species of helminths reproduce within their definitive hosts in the sense of producing stages which are infective to other hosts, only a very few species of intestinal helminths such as Strongyloides and Capillaria actually multiply in number within a host; for all other species of intestinal helminths each worm in the gut of a host is a result of a separate infection event. One important consequence of the cumulative gain of worms is that the number of infective stages shed by that host — its infectiousness — is related to the number of worms it contains. In epidemiological terms this means that the unit of study is the individual worm. The other important consequence of the accumulation of worms is that the occurrence of disease is related to the intensity of infection: infections with a few worms tend to be asymptomatic but as more worms are acquired, signs and symptoms of disease are more likely to occur.

In contrast with macroparasitic infections, the organisms classified as microparasites both reproduce and multiply within their hosts. For intestinal protozoa this means that a single infective stage can both establish an infection and then multiply so that the host in turn excretes large numbers of infectious stages. The infectiousness of a host is not therefore related directly to the degree of exposure to infection, and for epidemiological purposes the individual host is the unit of study. Finally, intestinal protozoa are superficially similar to intestinal helminths in that infected people are not necessarily diseased.

These biological characteristics of macro- and micro-parasites mean that the prevalence and intensity of infections are both important measures for evaluating programmes to control intestinal helminths, while for intestinal protozoa only the prevalence is of use. The prevalence of infections with intestinal parasites is defined as the proportion of the population that is infected, while the intensity is the average number of parasites within individuals in the population.

The basis of any procedure to evaluate control measures is the diagnosis of infections, and the microscopic examination of faeces for the eggs or larvae of helminths and for the trophozoites or cysts of protozoa is still the most widely used and practicable means to detect infections. This technique requires technical skill but is otherwise simple and inexpensive, and although it may lack in sensitivity for light infections, a diagnosis made by microscopy is usually species-specific. There are many books and manuals which provide details of microscopy and other methods to diagnose intestinal parasitic infections (2).

The next two sections will deal separately, and in more detail, with the specific characteristics of the biology, epidemiology and diagnosis of intestinal helminths and protozoa which need to be understood if the effectiveness of measures to control infections are to be evaluated.

Intestinal helminths

The focus here will be on the most common intestinal nematode parasites of humans: Ascaris lumbricoides, Trichuris trichiura, and the two species of hookworms, Necator americanus and Ancylostoma duodenale.

The distribution among hosts

Intestinal helminths are neither uniformly nor randomly distributed amongst individuals in a population, but are highly aggregated so that most individuals have few worms while a few people harbour disproportionately large worm burdens. This pattern of distribution is illustrated in Fig. 1 and is typical of all the major species of nematode parasites of humans. Field studies have repeatedly found that about 70% of the worms occur in 15-30% of the people. This minority of heavily infected people not only comprises the individuals most likely to suffer disease, they are also the major sources of infection in the community. Consequently, it is more important and certainly more practicable to control or eradicate morbidity due to intestinal helminths than to eradicate all infections. Morbidity and transmission can be reduced by treating the most heavily infected individuals, particularly children, and the advantages of such approaches have been recently
demonstrated by a combination of theoretical studies, practical evaluation and cost-effectiveness analysis (3, 4). These advances, together with a more critical assessment of the practicalities of delivering drugs (5, 6), have contributed to the development of control approaches aimed specifically at groups within communities which are most at risk of both infection and disease (4). Because the aim of such control measures is to reduce mean worm burdens and eliminate disease, the prevalence of infection is likely to be an inadequate means of evaluating such control programmes and it is necessary to assess changes in the intensity of infection in order to measure disease and transmission. This is necessary particularly because, as will be shown later, there is no direct relationship between the prevalence and intensity of infection. In order to appreciate this it is necessary to describe in more detail something of the variation in worm burdens that occurs among a population (7).

A population of worms within a person is typically in a state of flux in which old worms die and new worms are acquired by exposure to infective stages. Some aspects of the infection processes and the establishment of worms can be assessed by monitoring reinfection following treatment. Such studies indicate that some individuals are predisposed to heavy infections while others are consistently lightly infected. Predisposition is demonstrated by showing that the size of a worm burden acquired after treatment is positively associated with the intensity of infection before treatment. Such an association has been shown for all the major intestinal helminths (7), and this trend persists over at least two reinfection periods (8). Longitudinal studies confirm that this positive association reflects a direct relationship between the rate of reinfection and initial infection status. An additional, practical consequence of the aggregated distribution of parasites and of the tendency for some individuals to be consistently heavily infected is that a large sample size must be used to estimate mean intensity when assessing the effect of control measures.

**Infection in the community**

The aggregation of a large proportion of all worms in a small proportion of all people in a community is also seen within age groups, although the degree of aggregation varies with age and with the species of parasite. In hookworm infection, worms tend to be more aggregated among adults than among children (9), while for *T. trichiura* and *A. lumbricoides*, infections tend to be more highly aggregated among children.

Heavy infections may also be aggregated among families. Studies have shown that more families tend to contain individuals who are heavily infected with *T. trichiura* and *A. lumbricoides* than would be expected by chance, whereas families with a mixture of both heavy and lightly infected individuals are less common than would be predicted. Studies of these parasites in Mexico and Malaysia indicate that families also exhibit a predisposition to infection.

The relationship between age and prevalence shows some variation among the major intestinal hel-
infections. The peak prevalence of infections with *A. lumbricoides* and *T. trichiura* is usually reached by 5 years of age, while for hookworm infection the peak is reached in young adults (Fig. 2). For infections with *A. lumbricoides* a slight decline in prevalence is often observed in adulthood.

For most helminth species the initial rise in the intensity of infection with age closely mirrors the rise of prevalence, but the rise in intensity occurs at a slightly slower rate (Fig. 3). The age at which the highest mean intensity of infection occurs depends on the life span of the helminth species and is independent of local rates of transmission (10). For *A. lumbricoides* and *T. trichiura* the peak intensity of infections tends to occur among children aged 8-10 years, and for hookworm the peak occurs in adulthood.

The most important differences in the relationship between age and the intensity of infections with these species become apparent after the peak intensity has been attained. *Ascaris lumbricoides* and *T. trichiura* exhibit a marked decline in the intensity of infection after the peak in childhood, to reach a relatively stable but low level which then persists throughout adulthood (Fig. 3). Studies of hookworm in which burdens have been counted after expulsion by anthelmintic treatment (Fig. 3) indicate that the intensity attains a peak in adulthood (9).

These patterns show that the prevalence of infection with *A. lumbricoides* and *T. trichiura* may be similar in children and adults, but the children will tend to have larger worm burdens. For hookworm infections, in which both the prevalence and intensity of infection show a rise with age, more adults than children will be infected and they will have larger worm burdens.

**The relationship between intensity and prevalence**

In order to explain these relationships between age and infection, it is necessary to examine the relationship between prevalence and intensity (Fig. 4). The non-linear relationship between the prevalence of infection with *A. lumbricoides* and the mean worm burden is a direct consequence of the fact that most worms are aggregated in a few hosts while most other hosts are lightly infected. This relationship holds true even when egg counts are used to estimate worm burdens, and is characteristic of all the major intestinal nematode species.

The important practical consequence of this relationship is that even if control measures reduce the mean worm burden, and thus the prevalence of disease, there may be little change in the prevalence of infection. Prevalence of infection can provide a reasonable estimate of the mean intensity of infection when worm burdens are small: a decline in the mean worm burden from 10 to 5 worms is accompanied by a large fall in the prevalence (Fig. 4). In contrast, where average burdens are large, a significant reduction in the intensity of infection is not reflected in a similar change in prevalence. This is particularly true for *T. trichiura* where worm burdens often range from 50 to 100 worms. This helps to explain why the prevalence of infection with *A. lumbricoides* often declines in line with intensity in adulthood, but the prevalence of *T. trichiura* does so only rarely (11). This adds further weight to our contention that the prevalence alone is an inadequate measure of the status of infection with intestinal helminths, particularly in circumstances where infections are hyperendemic.

**Assessing the intensity and prevalence of infection**

The microscopical examination of faeces for the eggs or larvae of intestinal helminths is usually diagnostic for each species of infection and provides the prevalence of infection, although the eggs of the two species of hookworms cannot be readily distinguished. Determining the intensity of infections by treating people and counting the number of worms expelled is invaluable for research studies, but is not a practicable means of evaluating control programmes.

The reproductive biology of the parasites can introduce error in estimates of both the prevalence and intensity of infections. Female nematodes only produce eggs when they are sexually mature and have been fertilized by males, so infections with juvenile male worms do not result in egg laying. The most reported prevalence of infection will be an underestimate of the true prevalence because infections will not be detected in some individuals.

The most convenient means of estimating the intensity of infections is to quantify the density of eggs in faeces on the assumption that this is directly proportional to the number of worms in the intestine. Eggs counts are usually expressed as eggs per gram (epg) of faeces and there are several books or manuals which give details of techniques which can be applied to weighed stool specimens (2).

There are several sources of variation in egg counts which can make them unreliable estimates of the intensity of infections for individuals. Firstly, male worms do not produce eggs, so it has to be assumed that control measures do not affect the sex ratio of worms. Secondly, faecal egg counts have been found to vary from day to day within individuals (12). Thirdly, the fecundity of female worms is dependent on worm density (70). Finally, several studies have shown that egg counts before anthelmintic treatment are poorly correlated with the number of worms subsequently expelled (13). Although an egg count tends to be a poor estimate of the number of worms present in an individual’s gut, the use of group or sample averages overcomes some of the inherent variability and imprecision, and mean egg counts for large worms can be useful and representative of mean worm burdens. An important point is maintaining the consistency of sampling techniques throughout monitoring. For example, increasing the size of stool specimen examined will increase the sensitivity of sampling, and may give a false impression of an increase in prevalence of infection.

**Assessing the extent of morbidity in the community**

For many bacteria and viruses there is a close and simple correspondence between infection and disease. In contrast, for intestinal helminths the relationship between infection and disease is complex and disease is not an automatic outcome of infection. If we accept that infections with a few worms in an otherwise healthy host are asymptomatic and that illness is related to the intensity of infection, then it is apparent from the distribution of heavy infections that the occurrence of disease will be related to age. The relationship is complicated by
FIG. 2
COMPARISON OF TYPICAL AGE / PREVALENCE RELATIONSHIPS
COMPARAISON DE RELATIONS ÂGE / PRÉVALENCE CARACTÉRISTIQUES

Source: References (29, 30) — Références (29, 30).

FIG. 3
COMPARISON OF TYPICAL AGE / INTENSITY RELATIONSHIPS
COMPARAISON DE RELATIONS CARACTÉRISTIQUES ÂGE / INTENSITÉ DE L'INFESTATION

Source: References (9, 31) — Références (9, 31).

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FIG. 4
COMPARISON OF TYPICAL PREVALENCE / INTENSITY RELATIONSHIPS
COMPARAISON DE RELATIONS CARACTÉRISTIQUES PRÉVALENCE / INTENSITÉ DE L'INFESTATION

A. lumbricoides

T. trichiura

Hookworm — Ankylostome

Mean worm burden — Charge parasitaire moyenne

Mean intensity (eggs/g; 000s) — Intensité moyenne (œufs/g - en milliers)

Source: Reference (19) — Référence (19).
the fact that the occurrence of disease is not just related to the number of worms in a host, but is likely also to be related to the biomass of worms, to the duration of infection, and to the background health status of the host.

These factors mean three things: that disease is much less common than infection, that not all people will be affected by treatment, and that any changes in the health status of diseased individuals may be hidden when the community as a whole is studied. This failure to appreciate that helminth infections do not always cause disease, which has led to the apparent lack of effect of some control measures, may be a major reason for the failure to recognize the importance of helminth disease for human health (14).

There is a general acceptance of the view that very intense infections result in illness. For example, hookworms can cause severe anaemia, ascariasis can obstruct the intestine and trichuriasis can cause colitis, rectal prolapse and dysentery. However an understanding of the relationship between the intensity of infection and any clinical signs or symptoms has proved more elusive. This appears to be due to two main factors.

Firstly, the relationship between the intensity of infection and the pathogenesis of disease is not linear. Studies of the relationship between infection and morbidity indicate that although severe anaemia occurs when there are thousands of worms, a clinically important degree of anaemia can be caused by a few hundred worms, the precise number depending on the host’s iron status (15). This relationship occurs despite a constant blood loss per worm which might be expected to lead to a linear relationship. Studies of the protein-losing enteropathy caused by *T. trichiura* also indicate a non-linear relationship with worm burden.

The second reason for the lack of understanding of the relationship between the intensity of infection and disease is the difficulty of attributing the cause of symptoms to the multiplication of the parasite and the presence of the worm. This is in part the classical epidemiological problem of identifying the specific cause of illness or morbidity in a population subject to many different causes of ill-health. For helminth infections this is exacerbated by the absence of specific signs or symptoms. This problem has been addressed by intervention studies in which helminth infections have been treated by chemotherapy. Significant improvements in growth have been observed in children infected with hookworms, *A. lumbricoides* and *T. trichiura* (16, 17). Even more subtle consequences of infection are suggested by recent double-blind placebo trials which show significant improvement in the cognitive ability of malnourished children moderately infected with *T. trichiura* (18). These results suggest that even moderate helminth infections may have insidious consequences that are unlikely to be attributed in public health statistics. In one study of a village where helminths were hyperendemic, only 2% of actual morbidity had been reported to the health authorities (14).

Some insights into the relationship between infection and disease have been provided by a statistical analysis of appropriate data (19). If it is assumed that a threshold number of worms is associated with disease, then by using the relationship between the intensity and prevalence of infection (Fig. 4) it is possible to estimate the proportion of individuals who exceed some threshold number of worms and who are likely to be ill for any given prevalence of infection (Fig. 5). One of the conclusions of this analysis is that the threshold number of worms need not be defined precisely, since the form of the relationship between infection and disease is relatively insensitive to the threshold value, provided the value is relatively large. These analyses indicate that as the prevalence of infection rises, the presence of disease increases disproportionately. For example, if more than 25 *A. lumbricoides* are taken to cause disease, then almost half the population will suffer from disease when the prevalence of infection is 90%, but only 2% when the prevalence of infection is 70%. It is unsurprising that in areas where the prevalence of infection is stated to be “high”, studies of morbidity often reach very different conclusions about the public health significance of intestinal helminths. There is obviously a need for quantitative rigour in defining the prevalence of disease, both for determining the public health significance of helminths and for evaluating the effectiveness of control (19).

**Evaluating the control of intestinal protozoa**

The focus here will be on the three most common and important intestinal protozoan infections of humans in developing countries, *Entamoeba histolytica*, *Giardia duodenalis* and *Cryptosporidium parvum*, which respectively cause the diseases amoebiasis, giardiasis and cryptosporidiosis. It should be pointed out that infections with these and other species of intestinal protozoa also occur in industrialized countries in significant numbers, although infections tend to be epidemic rather than endemic and to occur within distinct social groups. The emphasis here will be on evaluating measures to control infections in developing countries.

**Assessing the extent of morbidity in the community**

Infections with intestinal protozoa are often asymptomatic. The reasons for this vary from species to species but are largely unknown. However the distinction between infection and disease is as important for protozoa as it is for helminths, although for different reasons.

Because a single cyst can result in the establishment of an infection, and because intestinal protozoa multiply, as well as reproduce within a host, the occurrence of disease is not as clearly related to the intensity of infection as it is for helminths, although it has been observed that oocysts, for example of *C. parvum*, are excreted in large numbers during diarrhoea. This suggests that there is a relationship between the multiplication of the parasite and the occurrence of disease, but why all infections do not cause disease when there is evidence of heavy infections is unclear.

Many people in developing countries show no signs or symptoms of disease when infected with intestinal protozoa. This raises the question of the role of asymptomatic cyst passers in the transmission of disease. People who are lightly infected with a species of intestinal helminths are probably not major sources of transmission, but infection with a single protozoan cyst can lead to the excretion of many millions of cysts each day. This has led to a debate about the risks to infected individuals of treating asymptomatic infections and, if such infections are not treated, the risks of infection and
disease to other members of the community. These issues should be considered in any control programme involving chemotherapy as a tool of control, but will not be dealt with here.

The consistent observation of asymptomatic infections raises questions about whether the organisms which parasitize asymptomatic individuals have the potential to cause disease or are inherently non-pathogenic strains, and about whether diseased people are different in some way from asymptomatic cyst passers because, for example, their immune response to infection modulates the occurrence of symptoms. These are largely theoretical questions and the differences in the biology of these organisms, coupled with the gaps in our knowledge, makes generalizations difficult. However, recent developments have increased our understanding of the biology and epidemiology of the three main intestinal protozoa which cause disease in humans, and this growth in knowledge may assist in evaluating control programmes.

Entamoeba histolytica can invade the wall of the large intestine to cause dysentery, and organisms can be carried in the blood to distant tissues and organs where abscesses may form (20). Other individuals, although infected, remain asymptomatic and only excrete cysts in their stools. There is a growing body of evidence from studies of isoenzymes, surface antigens, ribosomal RNA and DNA, that what was once considered to be a single species may in fact comprise two species which are morphologically indistinguishable but only one of which causes disease. If this is the case and if two species are created from what is currently classified as E. histolytica, then the diagnosis of infections with E. histolytica by direct microscopy of stools will no longer be possible and the epidemiology and significance of infections will have to be re-evaluated.

The taxonomy of what is here called Giardia duodenalis is disorganized: there are at least three other names in current use, including G. lamblia, G. intestinalis and Lamblia intestinalis. Again asymptomatic infections occur in many individuals while in others there is disease, typically characterized by diarrhoea and malabsorption. No symptom is unique to giardiasis, but a recent definition of clinical cases may be of assistance in control programmes (21). Infections and disease both tend to be chronic and may last for several months. There is some evidence for differences between strains of G. duodenalis, but there is no clear association yet with the occurrence of disease. The epidemiology of giardiasis could however be explained by the existence of strains with differing potential to cause disease, or by the development of partial immunity which ameliorates symptoms, but does not protect from reinfection.

The disease caused by C. parvum is a self-limiting watery diarrhoea with no particularly specific symptoms, and evidence from parasitological and serological surveys suggests that asymptomatic infections are common (22).

There are few symptoms of disease due to intestinal parasites which are characteristic or unique, and the clinical course of disease can be similar to other infectious diseases: in many parts of the world.
dysentery is more often caused by species of *Shigella* than by *E. histolytica*, while *Vibrio cholerae* on its own strains of *Escherichia coli* are more likely to be a cause of severe watery diarrhoea than *C. parvum*. Clinical judgement is not therefore a sound basis on which to assess the prevalence of disease due to intestinal protozoa, and a specific diagnostic technique should be applied for the purpose of evaluating control programmes.

**Assessing the prevalence of infections**

Infection with intestinal protozoa can be more difficult to diagnose than infection with intestinal helminths. Most currently-used techniques either rely on seeing cysts or vegetative stages in faeces, or use specific antibodies as a means of capturing parasite antigens from faeces. A diagnosis is therefore made indirectly and cysts, trophozoites or antigen can be diluted, obscured or damaged, so that infections may not be detected. Current diagnostic techniques are neither very sensitive nor very specific. Assessing the accuracy of the diagnostic test to be used in the evaluation of control programmes is important if the results are to be related to the effects of control.

Nevertheless the microscopical examination of faeces is still the standard and most specific means of diagnosing intestinal protozoa, even if it may lack sensitivity. Ideally both fresh faeces and samples subjected to a concentration technique should be examined: fresh faeces should be examined if only trophozoites are being passed or if a diagnosis of amoebiasis is to be made (see below), and although concentration techniques destroy trophozoites, they serve to extract cysts from faeces if they are present only in small numbers, thereby increasing the sensitivity of the examination. The concentration technique to be used should be selected carefully, depending on the protozoan species of interest (23).

Serological tests for infection have limitations. They often cannot detect very recently-acquired infections because it may take 10 days or more before antibodies can be detected in the blood. Antibodies in general may persist long after the infection has resolved or been treated, although there is some evidence that different classes of antibodies may be of use in diagnosing current infections. The serodiagnosis of parasitic diseases has recently been reviewed by Maddison (24). Serodiagnosis, as other diagnostic techniques, allows the calculation of the rate of new infections. Control programmes that reduce transmission would reduce the rate of increase of positive diagnoses. For long-lasting antibodies, this would be shown as a reduction in the seropositivity with age compared with precontrol, and for shorter-term antibodies, a reduction in the seropositivity overall.

A potentially more useful and highly specific means of diagnosing intestinal protozoa lies in the use of monoclonal antibodies to detect parasite antigens in faeces. In theory an assay to detect antigens expressed only by pathogenic species or strains could provide a tool to distinguish strains of parasites which cause disease. A specific and sensitive antigen-capture ELISA also has advantages over microscopy because large numbers of samples can be screened at once. This would have obvious value if a large-scale control programme were to be evaluated. Until monoclonal antibodies can be identified which are specific to pathogenic species or strains, polyvalent antiserum is generally likely to be of most use in diagnosing any intestinal protozoan infection. Yet whatever antibodies are used, sufficient controls should be used when doing such tests to control for non-specific binding as there may be antigens in faeces which may affect the performance of the assay.

Like most protozoa, *Entamoeba histolytica* has traditionally been diagnosed by the microscopic examination of stools for cysts or trophozoites. Differentiation from the morphologically similar but smaller cysts of *E. hartmanni* requires measurement.

Another problem with diagnosing infections with *E. histolytica* is that the parasite may not be excreted in the faeces of people with amoebic abscesses, and abscesses may develop without preceding symptoms of diarrhoea or dysentery. Finally, if there is enough evidence to justify reclassifying *E. histolytica* as two separate species as discussed above, then there will be a need for tools to distinguish between the species, such as indirect fluorescence antibody tests or an ELISA. This uncertainty about what is and is not *E. histolytica* makes it difficult to discuss the significance of seeing cysts alone in faecal samples. Nevertheless whatever the result of the taxonomic debate, it is clear that in order to diagnose the disease amoebiasis, one must see trophozoites containing ingested red blood corpuscles during a microscopic examination of fresh faeces.

Infections with *G. duodenalis* can be diagnosed accurately by the microscopic examination of fresh stool smears for cysts and trophozoites, which are characteristic. Microscopy has been reported to miss between 10% and 50% of infection (25), probably because cysts are known to be excreted intermittently, although experience at diagnosing *G. duodenalis* is likely to be an important influence on the likelihood of detecting infections.

People with diarrhea due to *C. parvum* usually excrete large numbers of oocysts which are easily found in faeces, but they are smaller than the cysts of *G. duodenalis* or species of amoeba, and do not stain with iodine, so that in addition to difficulties finding when present only in small numbers. Concentration techniques and staining procedures may need to be applied, all of which increase the time and costs of testing faecal samples. Oocysts have been detected by using antibodies conjugated with fluorescent dyes and an ELISA has been reported, and techniques for diagnosing *C. parvum* have recently been reviewed by Casemore (22).

**Distribution of infections and morbidity among hosts**

The specific characteristics of the epidemiology of each species of intestinal protozoal infection are important factors to be considered when attempting to evaluate control programmes: the patterns of infection and disease differ considerably between species of protozoa and between different age groups within the community. For example, Fig. 6 shows that infections with *G. duodenalis* are more common in children living in an urban slum in Bangladesh than among adults, while the opposite is true for *E. histolytica*.

Some people are consistently more likely to be infected than others, and infections generally tend to be most common in children. Giardiasis is common amongst children, travellers and people with im-
mune deficiency diseases: groups which are assumed to be immunologically naive or deficient. Repeated infections are associated with less severe symptoms or may be asymptomatic. For these reasons, host responses are believed to partially explain the observation that many infected people in developing countries do not have symptoms of disease.

Although risk factors for disease can reveal something about the occurrence of asymptomatic infections, the risk factors for infection are not necessarily the same as the risk factors for disease. Adults infected with *E. histolytica* have been found to be 10 times more likely than children to develop amoebiasis, while adult men are 3-6 times more likely to develop amoebiasis than women (20).

**Distribution of infection and disease in the community**

In developing countries intestinal protozoa are typically endemic with transmission occurring all year round, perhaps with seasonal fluctuations related to temperature and rainfall. Infections are mainly associated with poor sanitation and a lack of clean water to maintain personal hygiene, although there is very little clear epidemiological data on the routes of infection.

The role of animals in the transmission of intestinal protozoa varies from species to species. Although more than 40 species of animals have been found to be infected with *C. parvum*, and contact with animals such as calves can lead to infections, it is likely that much transmission occurs directly from person to person or through contaminated water supplies. There is still a debate about whether *G. duodenalis* is a true zoonosis, and the term “reservoir of infection” may be preferable. Studies have shown that beavers can be infected with organisms which are morphologically indistinguishable from those derived from humans, and these animals live in water courses in areas of North America where there have been outbreaks of infections among campers or local inhabitants. Of more relevance to developing countries is that *G. duodenalis* cysts have been detected in the stools of goats and sheep in Egypt (26). Animal reservoirs of potential infection should thus be considered when evaluating measures to control *G. duodenalis* and *C. parvum*, but there is no evidence that *E. histolytica* is commonly transmitted between animals and humans.

**Discussion and conclusions**

This review has attempted to identify the biological and epidemiological aspects of intestinal helminth and protozoan infection which are most relevant to evaluating control approaches. It is apparent that these groups of infections share a number of characteristics: both occur in the intestine, have external transmission routes, are associated with poverty and poor sanitation, and are diagnosed by coprological methods. Despite these superficial similarities it is equally apparent that control of these two groups of infections requires very different approaches to evaluation. In evaluating control of helminth infection it is intensity which provides the most meaningful measure of both morbidity and transmission. The most commonly used measure,
prevalence, may provide a misleading estimate of the success of control, particularly in those hyper-endemic communities most in need of the control programmes. Evaluating helminth intensity, however, requires careful attention to the structure of the population sample examined. Evaluation of the control of protozoan infections, in contrast, can usefully be achieved using prevalence measures. The complexity for protozoa arises from the need to differentiate pathogenic species and strains from ubiquitous harmless infections.

The development of improved approaches to evaluating the control of intestinal parasites will involve two major areas of study. For the evaluation of helminths, greater understanding is required of the spatial distribution of infections, particularly multiple-species infections, to allow more precise design of sampling procedures. For the evaluation of protozoan infection, the major need is for improved field procedures for differentiating pathogenic species and strains.

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SUMMARY

Intestinal parasitic infections are among the most common infections of humans in developing countries, but the resources available for their control are severely limited. Careful evaluation of control measures is essential to ensure that they are cost-effective. The evaluation of the effects of control on intestinal helminths and intestinal protozoa requires an understanding of the different epidemiological patterns of these two groups of parasites.

The transmission dynamics and morbidity associated with the major helminth infections (Ascaris lumbricoides, Trichuris trichiura and the hookworms) are dependent on the size of the worm burdens. Thus the important parameter for evaluating the impact of control on morbidity and transmission is the intensity of infection, which can be assessed by determining the mean density of parasite eggs in faecal specimens. Estimation of intensity is subject to systematic errors, however, due to the complex pattern of worm burden distributions. The frequency distribution of burdens is highly over-dispersed, and individuals exhibit predisposition to particular levels of infection. Furthermore, mean intensity is age-dependent, in a species-specific manner, and is clustered spatially and within families. These complex patterns imply that the estimation of intensity is exceptionally sensitive to the size and demographic structure of the population sample selected for assessment. They also have the effect that prevalence estimates, the most commonly used measures of infection in communities, can seriously mislead. Paradoxically, prevalence is least useful where infection is most common because the relationship between prevalence and intensity is most markedly non-linear when the prevalence is high. Thus in areas where control is most needed, evaluation using prevalence might suggest that control had failed while evaluation by intensity would, correctly, show the measure of success.

With the major protozoan infections (Entamoeba histolytica, Giardia duodenalis and Cryptosporidium parvum) an estimate of intensity is of little value and the central parameter for evaluation is prevalence. Prevalence does exhibit age and spatial heterogeneity, which may be species-specific, so there remains a need to ensure a consistent sample structure, although this is less critical than for the helminths. The major constraint on evaluating the control of protozoan infections is the need to identify pathogenic species and, in some cases, pathogenic strains. Harmless commensal protozoans are ubiquitous and often morphologically very similar to pathogens, but their control is both unnecessary and impracticable. Species such as E. histolytica appear to exist as strains with differing pathogenicity; thus control will be cost-effective only if the focus is on pathogenic strains. Effective diagnosis is therefore central to the evaluation of the control of protozoan infections. Microscopy of faeces will usually be adequate to identify the major species, and is appropriate for G. duodenalis and C. parvum. Identifying the pathogenic strains of E. histolytica requires specialized laboratory methods, none of which are currently available for routine field use.

RÉSUMÉ

Evaluation des mesures de lutte contre les parasitoses intestinales

Les parasitoses intestinales comptent parmi les infections les plus courantes dans les pays en développement, mais les moyens dont on dispose pour les combattre sont des plus limités. Une évaluation soigneuse des mesures de lutte est essentielle pour en assurer la rentabilité. L'évaluation des effets de la lutte contre les helminthes et les protozoaires intestinaux suppose la connaissance des différents aspects que peut revêtir l'épidémiologie de ces deux groupes de parasites.

La dynamique de la transmission des principales helminthiases (ascariasidies, trichocéphalose et ankylostomiasis) et la morbidité qu'elles suscitent dépendent de l'importance de la charge parasitaire. C'est donc l'intensité de l'infection, que l'on peut apprécier par la détermination de la densité moyenne des œufs de parasites dans des échantillons de selles, qui constitue le paramètre à prendre en considération pour évaluer l'impact des mesures de lutte sur la morbidité et la transmission. Cependant, étant
donné que la charge parasitaire n’est pas répartie de façon simple, cette estimation peut être entachée d’erreurs systématiques. La distribution de fréquence de la charge parasitaire est très largement dispersée et les individus peuvent être prédisposés à une valeur particulière de la charge infestante. De plus, l’intensité moyenne de l’infestation est liée à l’âge, selon l’espèce en cause, et elle présente des agréments dans l’espace comme au sein des familles. Il résulte de cette complexité que l’estimation de l’intensité est exceptionnellement sensible à la taille et à la structure démographique de l’échantillon de population choisi pour l’évaluation. Il peut également s’ensuivre que la prévalence estimative, qui est le paramètre le plus fréquemment utilisé pour évaluer l’intensité de l’infestation dans une collectivité, peut conduire à de graves erreurs d’interprétation. Paradoxalement, c’est lorsque la parastose est très répandue qu’elle est le moins utile, du fait que la relation entre la prévalence et l’intensité de l’infestation est d’autant moins lineaire que la prévalence est plus forte. Ainsi, dans les régions où la lutte est le plus nécessaire, une évaluation basée sur la prévalence pourrait donner à penser que les mesures de lutte ont échoué alors qu’une évaluation basée sur l’intensité permettrait d’apprécier correctement le succès obtenu.

Dans le cas des principales protozooses (Entamoeba histolytica, Giardia duodenalis et Cryptosporidium parvum), l’intensité estimative n’offre guère d’intérêt et c’est la prévalence qui constitue le paramètre important pour l’évaluation. Comme la prévalence présente une hétérogénéité selon l’âge et dans l’espace, hétérogénéité qui peut être caractéristique de l’espèce, il est nécessaire de s’arranger pour que l’échantillon ait une structure uniforme, encore que ce facteur soit moins déterminant que dans le cas des helminthes. Lorsqu’on cherche à évaluer les résultats de la lutte contre les protozooses, la principale contrainte consiste dans la nécessité d’identifier l’espèce, voire la souche pathogène en cause. Les protozoaires commensaux inoffensifs sont omniprésents et leur morphologie est souvent très semblable à celle de leurs homologues pathogènes, mais il est inutile et d’ailleurs impossible de les éliminer. Dans l’espèce E. histolytica, par exemple, il existe des souches plus ou moins pathogènes, aussi la lutte ne sera-t-elle rentable que si elle se concentre sur les souches véritablement pathogènes. Il est donc capital de disposer de moyens de diagnostic efficaces pour évaluer les résultats de la lutte contre les protozooses. L’examen d’un échantillon de selles entre larme et lamelle suffit en général pour identifier les principales espèces, et il convient bien pour G. duodenalis et C. parvum. L’identification des souches pathogènes de E. histolytica nécessite en revanche des méthodes spécialisées de laboratoire qui ne sont pas actuellement utilisables en routine sur le terrain.

REFERENCES — RÉFÉRENCES

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