Epidemiological evidence for a differential effect of hookworm species, *Ancylostoma duodenale* or *Necator americanus*, on iron status of children

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**Background**

The hookworms, *Ancylostoma duodenale* and *Necator americanus*, cause significant gastrointestinal blood loss. In clinical studies, greater blood losses have been reported with *A. duodenale*. However, there has been no evidence that endemic *A. duodenale* infection has greater impact than *N. americanus* infection on the iron status of populations.

**Methods**

In a sample of 525 school children in Pemba Island, Tanzania, we compared the degree of anaemia and iron deficiency associated with the two hookworm species at the individual and community (i.e. school) levels. Multiple regression was used to control for infection intensities and other child characteristics.

**Results**

In the 492 children with hookworm positive faecal cultures, haemoglobin and ferritin concentrations decreased with increasing proportions of *A. duodenale*. Among children with only *N. americanus* larvae, the prevalence of anaemia was 60.5% and the prevalence of ferritin <12 µg/l was 33.1%, while in children with >50% *A. duodenale* larvae, the respective prevalences were 80.6% and 58.9%. When children were grouped by the prevalence of *A. duodenale* at the school level, children from high prevalence (>20%) schools had significantly worse iron deficiency and anaemia than children from low prevalence schools.

**Conclusions**

The species of hookworm being transmitted in a community influences the burden of iron deficiency anaemia in the community, and should be considered in prioritizing and planning programmes for hookworm and anaemia control.

**Keywords**

Hookworms, *Ancylostoma duodenale*, *Necator americanus*, school children, iron deficiency, anaemia

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Hookworms infect an estimated 1.3 billion people globally.¹ Iron-deficiency anaemia caused or exacerbated by intestinal blood loss is the most outstanding feature of hookworm infection.² ³ Blood loss is caused when hookworms attach to and feed from the intestinal mucosa, and the magnitude of blood loss is directly related to the number of adult worms residing in the intestine.⁴ The balance between iron intake and iron loss from intestinal bleeding determines the risk and severity of iron-deficiency anaemia from hookworm infection.⁵

There are primarily two species of hookworms that infect humans: *Ancylostoma duodenale* and *Necator americanus*.⁶ *Necator americanus* tends to thrive in more tropical climates, while *A. duodenale* favours cooler, drier climates. However, their geographical distributions overlap considerably, and both species are endemic to many areas.² Hookworms are transmitted when hookworm eggs excreted in human faeces are incubated in appropriate soil conditions, hatch into larvae and enter a human host through the skin. In contrast to *N. americanus*, *A. duodenale* can infect humans by the oral as well as the percutaneous route⁷ and may undergo arrested development in human organ systems in its larval stage.⁸
From a morbidity standpoint, the most important difference between the two species is that A. duodenale causes approximately five times greater blood loss than N. americanus. This has been demonstrated in clinical studies in which isotopically labelled red blood cells were injected into hookworm-infected individuals, and the faecal excretion of the label was measured before and after deworming. Estimates from individual studies have found 2- to 10-fold higher blood losses with A. duodenale than with N. americanus.

However, there has been no evidence that endemic A. duodenale infection has greater impact than N. americanus infection on the iron status of populations. The population biology of hookworms, the host-parasite interaction, and iron absorption in humans may adapt in ways that prevent the burden of hookworm anaemia from becoming overly great in stable human populations. Such compensation strategies may prevent species related differences in blood loss per hookworm from manifesting into differences in the prevalence and intensity of iron-deficiency anaemia in human populations.

Because of the difficulty of measuring actual numbers of worms in population studies, most studies of hookworm infection and iron-deficiency anaemia in communities have used faecal egg counts to determine the presence and severity of hookworm infection. By this method, the two hookworm species cannot be distinguished, because their eggs have similar microscopic appearance. Thus, there has been no epidemiological evidence that the species of hookworm being transmitted in a community has a meaningful impact on the iron status of the population.

We have studied the epidemiology of hookworm infection and iron-deficiency anaemia in schoolchildren in Pemba Island, Zanzibar. Hookworms are highly endemic on the island, and both species were believed to be present. In the course of an ongoing evaluation of the impact of school-based deworming on children's nutritional status, we determined the species of hookworm infection in a sample of 525 children from 10 randomly selected communities. Infection intensities and iron status were also assessed. Our objectives were: (1) to describe the distribution of the two hookworm species across the island, (2) to determine whether children infected with A. duodenale have worse iron status than those infected with N. americanus, and (3) to demonstrate whether communities where A. duodenale is highly endemic have greater burdens of iron-deficiency anaemia than communities primarily infected with N. americanus, controlling for other factors.

Methods

Study area and sample

Pemba Island, the smaller of the two islands of Zanzibar, United Republic of Tanzania, lies 40 km off the East African coast, 5°S of the equator and is classed as a continental island with humid tropical climate. The northeast monsoon blows from October to December and is characterized by short rains. The southwest monsoon brings the long rains from mid-March to mid-May. The temperatures rarely exceed 34° or fall below 21°C.

Pemba is densely populated with 330 inhabitants per km². The island is divided into four districts of roughly equal size. About 15 000 people live in each of the three main towns of Wete, Chake-Chake and Mkoani, the rest of the population being scattered in numerous villages. The economy of the inhabitants is mainly based on farming and fishing. The primary crops consist of subsistence agriculture, with some clove and coconut plantations.

The sample for the present study was selected from children included in the baseline evaluation survey for the Zanzibar school-based deworming programme. For the evaluation, 12 schools were randomly selected stratified by district, and 3605 children in morning classes of grades 1–4 in those schools participated in the survey. The sample for the present study included 570 children, drawn as a systematic random subsample. Specifically, every seventh child surveyed from 10 of the 12 schools was included. Children from the first school were not included because the method for culturing hookworm larvae was not yet in place, and children from the last school were not included because we had already exceeded our intended sample size of 500 children.

The study was approved by the internal review boards of The Johns Hopkins University, the Ministry of Health of Zanzibar, and the World Health Organization.

Assessments

Survey data were collected in the schools by specially trained staff of the Ministry of Health of Zanzibar. On the day before the survey, plastic containers were distributed to each class and the children were asked to bring a stool sample to school the next day. Over 95% of children returned a faecal sample. Faecal hookworm egg counts were determined by the Kato-Katz technique. To determine hookworm species, cultures were successfully obtained for 525 of the 570 children selected for the study. The Harada-Mori technique modified according to Garcia & Bruckner was used in order to increase the efficiency of the culture method. Approximately 1 g faeces was mixed with active granular charcoal, and some water was added in the case of hard stools, to obtain an homogeneous paste. Two microscope slides were folded in a piece of absorbent paper and placed in a Petri dish with a diameter of 9 cm. The stool specimens were smeared carefully on the surface of the absorbent paper and 5–6 ml of distilled water were added to the Petri dish, without reaching the stool level. The cultures were covered and labelled and left at room temperature (26–30°C) in a shady place. The positivity of the cultures was checked with a dissecting microscope and after 7–10 days the cultures were transferred to a test tube. The larvae were killed by heating (100°C) in water for 2–3 min and then fixed with 10% formalin. The sediments were measured and a representative sample (usually 1/3 or 1/4) was examined for larvae that were identified and counted. The counts were then multiplied by 3 or 4 according to the proportion of sediment examined.

Urine samples were collected from 100% of children, and microhaematuria was diagnosed using Hemastix test strips (Ames Laboratories, Inc., Elkhart, IN). In this population microhaematuria screens for urinary schistosomiasis (Schistosoma haematobium) infection with 69% sensitivity and 89% specificity. Blood samples were collected by venipuncture from all children to assess iron status. Haemoglobin was determined by the HemoCue method (HemoCue AB, Angelholm, Sweden) and erythrocyte protoporphyrin was determined using a front-face haemato fluorometer (Aviv Biomedical Inc., Lakewood, NJ). A thin blood film was stained with Giemsa and malaria parasites
were quantitated against leukocytes using standard methods. The remaining blood was allowed to clot at room temperature, and serum was collected by centrifugation. Sera were stored at −70°C for up to 4 months. Serum ferritin was determined on 442 samples (84% of study children) using a fluorescence-linked immunoassay (DELFIA System by Wallac, Gaithersburg, MD). Missing data for serum ferritin were mainly due to mislabeling of specimens, and losses in transport.

**Statistical analysis**

Distributions of faecal egg counts, serum ferritin and erythrocyte protoporphyrin were skewed to high values, so geometric means are presented. Anaemia was defined as haemoglobin <11 g/dl. This is lower than the WHO-recommended cutoff for anaemia, but a lower cutoff screens more efficiently for iron-deficiency anaemia in black populations. A haemoglobin cutoff of 9 g/dl was used to define moderate-severe anaemia. Cutoffs for protoporphyrin are not well-defined. In these analyses values >120 μmol/mol heme were considered indicative of severe iron-deficient erythropoiesis. Serum ferritin <12 mg/l was used to indicate exhausted iron stores.

The prevalences of *A. duodenale* and *N. americanus* infections were examined for the entire sample, and by school. To compare the effect of the two species in individual children, children with hookworm positive larval cultures were grouped into those with only *N. americanus* larvae, those with 1–50% *A. duodenale* larvae, and those with >50% *A. duodenale* larvae. The latter group includes 11 children with apparently pure *A. duodenale* infections (i.e. no *N. americanus* larvae found). *Necator americanus* was highly prevalent in all communities surveyed, but the prevalence of *A. duodenale* ranged from 2% to 88% (Figure 1). To examine the effect of species on community burden of iron-deficiency anaemia, children in four schools with >20% prevalence of *A. duodenale* were compared to children in six schools with <20% prevalence.

In both individual and community level analyses, multiple regression was used to test the effect of hookworm species on measures of iron status. In individual level analyses the hookworm species variable was an ordinal variable with three values: 0 if pure *N. americanus*, 1 if 1–50% *A. duodenale*, and 2 if >50% *A. duodenale*. In the community level analyses, the hookworm species variable represented low prevalence versus high prevalence schools. The models included all child characteristics that differed between hookworm species groups, or that we knew to be associated with iron status from previous analyses. Adjusted mean values and standard deviations for iron status measures were calculated by analysis of variance.

Whether and how to control for the intensity of hookworm infection presented a dilemma. Because the blood loss caused by hookworm infection is directly proportional to the number of adult worms in the intestine, differences in intensity (i.e. worm burdens) of *A. duodenale* and *N. americanus* infections could confound the comparison of iron status between individuals or communities infected with the two species. We measured intensity of infection by faecal egg counts, but these cannot be directly compared between the two species because *A. duodenale* produces 2–3 times more eggs per adult worm than does *N. americanus*. Furthermore, there was not a simple way to correct the faecal egg counts from the Kato-Katz method to reflect the relative worm burdens of the two species.

Because a given number of eggs/g faeces represents fewer *A. duodenale* worms than *N. americanus* worms, controlling for hookworm eggs/g faeces might bias against finding a true species-related difference in iron status. However, it protects us from attributing to species a difference in iron status that was truly caused by greater worm burdens. We carried out analyses with and without adjustment for hookworm eggs/g faeces, and found it changed the results very little. We present results of analyses with adjustment for hookworm eggs/g faeces, a conservative approach. To adjust for hookworm eggs/g faeces, an ordinal categorical variable was included in the multivariate regression models, coded as 0 if 0 eggs/g, 1 if 1–1999 eggs/g, 2 if 2000–3999 eggs/g, and 3 if 4000–5999 eggs/g, and 4 if ≥6000 eggs/g faeces. The multiple $R^2$ for the models were highest when we used the variable in this form, rather than geometric mean eggs/g or other categorical forms. Data were analysed using Systat statistical software (SPSS, Inc., Chicago, IL).

**Results**

**Prevalence and geographical distribution of hookworm species**

Based on the faecal cultures, 33 children (6.3%) were not infected with hookworms, 11 (2.1%) were infected with only *A. duodenale*, 340 (64.8%) were infected with only *N. americanus*, and 141 (26.9%) were infected with both species of hookworm (Table 1). The prevalence of hookworm infection based on faecal cultures was 93.7%, and based on Kato-Katz method was 96.2%. The overall agreement for hookworm positivity between the faecal culture and Kato-Katz methods was 91.4% (480/525). Only four of the 525 children studied, less than 1% of the sample, were hookworm negative by both methods.
Table 1 Number of faecal samples diagnosed with hookworm infection by Kato-Katz method and faecal culture method

<table>
<thead>
<tr>
<th>Faecal culture result</th>
<th>Kato-Katz result</th>
<th>Positive for A. duodenale only</th>
<th>N. americanus only</th>
<th>A. duodenale + N. americanus</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative</td>
<td></td>
<td>4</td>
<td>3</td>
<td>11</td>
<td>20 (3.8%)^a</td>
</tr>
<tr>
<td>Positive</td>
<td></td>
<td>29</td>
<td>8</td>
<td>329</td>
<td>139</td>
</tr>
<tr>
<td>All</td>
<td></td>
<td>33 (6.3%)^b</td>
<td>11 (2.1%)</td>
<td>340 (64.8%)</td>
<td>525</td>
</tr>
</tbody>
</table>

^a Column per cents.
^b Row per cents.

The prevalence of N. americanus infection was uniformly high in all 10 schools surveyed, but the prevalence of A. duodenale varied greatly, from 2% to 88% (Figure 1). Four schools (Michezenzani, Tumbe, Msuka, and Mgogoni) were considered highly endemic for A. duodenale with prevalences of 42–88%, while the remaining six schools had prevalences below 18%. The four schools with high prevalence of A. duodenale were located at opposite ends of the island, and did not share any obvious geographical characteristics (Figure 2). Because A. duodenale transmission may exhibit seasonality, the dates of the survey in each school are included in Figure 2. The heavy rains began as the survey team moved from Chokocho to Ngombeni school, and continued for the duration of the study. The four schools with high prevalence of A. duodenale were surveyed during the heavy rains, but so were Ngombeni, Kizimbani and Shengejuu which had low prevalences.

**Hookworm species and individuals’ iron status**

The characteristics of children with only N. americanus infection did not differ significantly from those infected with A. duodenale (Table 2). The children were on average 10 years old, and about half were girls. About one-fourth of children had microhaematuria, an indicator of urinary schistosomiasis, and around 60% were positive for Plasmodium falciparum. Trichuris trichiura and Ascaris lumbricoides infections were common. The prevalence and intensity of these infections did not differ significantly between hookworm species groups.

The prevalence and intensity of hookworm infection, assessed by the Kato-Katz method, did not differ significantly between the hookworm species groups, but were significantly lower in children with negative faecal cultures (Table 2). The distribution of faecal egg counts assessed by the Kato-Katz method was similar between the hookworm species groups (Figure 3).

By all indicators, the iron status of children infected with A. duodenale was worse than those infected with only N. americanus, and haemoglobin and serum ferritin values became progressively worse according to the percentage of A. duodenale larvae found (Table 3). Overall there is a consistent pattern of worse iron status in children with more A. duodenale infection. The differences between groups was most significant for serum ferritin, the indicator most specific to iron deficiency.

**Hookworm species and community burden of iron deficiency and anaemia**

Compared to children in schools with low prevalence of A. duodenale, children in the four schools with high A. duodenale prevalence were slightly older and had a higher prevalence of microhaematuria (Table 4). The prevalence and intensity of T. trichiura or A. lumbricoides infection did not differ between children in the two groups of schools. However, the prevalence of hookworm infection and hookworm faecal egg counts were significantly higher in children in the schools with high A. duodenale prevalence. The difference in the hookworm faecal egg counts was apparent both in the mean values (Table 4) and in the distribution of values (Figure 4).

After adjusting for these differing characteristics between the groups, children in the high prevalence schools had significantly
Table 2  Characteristics of study children by species of hookworm infection determined by faecal cultures

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Negative culture (n = 33)</th>
<th>N. americanus larvae only (n = 340)</th>
<th>A. duodenale*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>10.4 ± 1.5^b</td>
<td>10.5 ± 1.9</td>
<td>11.0 ± 2.1</td>
</tr>
<tr>
<td>Sex (% girls)</td>
<td>42.4%</td>
<td>51.0%</td>
<td>45.9%</td>
</tr>
<tr>
<td>Microhæmatuna^c</td>
<td>24.2%</td>
<td>23.4%</td>
<td>24.3%</td>
</tr>
<tr>
<td>Malaria parasitaemia</td>
<td>60.6%</td>
<td>63.3%</td>
<td>60.7%</td>
</tr>
<tr>
<td>T. trichuria prevalence</td>
<td>93.9%</td>
<td>97.0%</td>
<td>96.4%</td>
</tr>
<tr>
<td>eggs/g faeces</td>
<td>525 (73, 3763)^d</td>
<td>633 (117, 3439)</td>
<td>577 (108, 1856)</td>
</tr>
<tr>
<td>A. lumbricoides prevalence</td>
<td>72.7%</td>
<td>71.5%</td>
<td>71.2%</td>
</tr>
<tr>
<td>eggs/g faeces</td>
<td>239 (6, 9072)</td>
<td>240 (6.9691)</td>
<td>233 (6, 9576)</td>
</tr>
<tr>
<td>Hookworms^e prevalence</td>
<td>87.9%</td>
<td>96.8%</td>
<td>98.2%</td>
</tr>
<tr>
<td>eggs/g faeces</td>
<td>258 (44, 1499)</td>
<td>608 (102, 3607)</td>
<td>844 (188, 3790)</td>
</tr>
</tbody>
</table>

^a Includes 11 samples in which only A. duodenale larvae were found, and 141 samples in which both species were found.
^b Mean ± SD
^c An indication of urinary schistosomiasis.
^d Geometric mean (±1 SD, ±1 SD)
^e Prevalence and intensity of hookworm infection by Kato-Katz method.

Figure 3  Distributions of hookworm faecal egg counts by hookworm species category determined by larval culture. Numbers of children in species categories: culture negative, 33; N. americanus only, 340; <50% A. duodenale, 113; >50% A. duodenale, 39. Distributions are not significantly different by χ² test.

Discussion

These results indicate that infection with A. duodenale in children and heavy transmission of A. duodenale in school communities is associated with a greater burden of iron-deficiency anaemia than infection with N. americanus. Previous claims of the greater pathogenicity of A. duodenale have been based on highly varying estimates of greater blood loss in A. duodenale infection. To our knowledge, this is unique epidemiological evidence that the previously measured difference in blood loss translates into a greater burden of hookworm-related anaemia in individuals and communities infected with A. duodenale.

The degree of iron-deficiency anaemia caused by hookworm infection depends on the number of adult worms inhabiting the gut, the duration of infection, the iron stores and intake of the infected individual and, as we have attempted to demonstrate, the species of hookworm. Ideally, proof of species
Table 3: Iron status of hookworm-infected children according to degree of A. duodenale infection determined by faecal culture

<table>
<thead>
<tr>
<th>Iron status indicator</th>
<th>N. americanus larvae only (n = 340)</th>
<th>A. duodenale &lt;50% of larvae (n = 113)</th>
<th>≥50% of larvae (n = 39)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haemoglobin (g/dl)</td>
<td>Mean ± SD: 10.4 ± 1.5</td>
<td>10.3 ± 1.5</td>
<td>9.8 ± 1.5</td>
</tr>
<tr>
<td>% &lt;11</td>
<td>60.5</td>
<td>64.5</td>
<td>80.6</td>
</tr>
<tr>
<td>% &lt;9</td>
<td>14.0</td>
<td>18.3</td>
<td>22.8</td>
</tr>
<tr>
<td>Protoporphyrin (µmol/mol heme)</td>
<td>Geometric mean (+1 SD, -1 SD)</td>
<td>97 (58, 162)</td>
<td>109 (65, 183)</td>
</tr>
<tr>
<td>% &gt;120</td>
<td>29.6</td>
<td>36.9</td>
<td>32.9</td>
</tr>
<tr>
<td>Ferritin (µg/l)</td>
<td>Geometric mean (+1 SD, -1 SD)</td>
<td>14.5 (7.7, 27.5)</td>
<td>13.4 (7.2, 23.4)</td>
</tr>
<tr>
<td>% &lt;12</td>
<td>33.1</td>
<td>50.7</td>
<td>58.9</td>
</tr>
</tbody>
</table>

* Values are predicted from analysis of variance, adjusted for hookworm eggs/g faeces determined by Kato-Katz method, age, height-for-age Z score, malaria parasitaemia, and sex.

b Linear trend in indicator by hookworm species category significant, P < 0.05.
c Linear trend in indicator by hookworm species category significant, P < 0.001.

d Differences in the impact on iron status of individuals would be based on measurement of all of these factors. In reality, such a study is nearly impossible to conduct. To account for the duration of infection, one would have to begin with an uninfected individual, and follow longitudinally the course of infection both in terms of species and number of worms, the iron intake and bioavailability of the diet, and the iron status of the individual. Such a study would illuminate our understanding of iron balance in hookworm infection, the role of hookworm species, and particularly the adaptations that might occur as haemoglobin levels become acutely low. However, the technical and ethical difficulties of such an observational study are likely prohibitive.

In weighing the strength of the present epidemiological evidence, it is useful to consider each of the four factors listed above. We measured intensity of infection by faecal egg counts, not by expulsion and enumeration of adult worms. The relationship between faecal counts and number of worms is different for the two species by a factor that is not precisely known. Adult female A. duodenale produce more eggs than do N. americanus, and the male to female ratio of adult worms is higher for A. duodenale than for N. americanus. This is problematic since we would like to compare the effect of species at similar levels of worm burdens. One could try to account for the differences by mathematically modelling the relationships, but the arithmetic
relationships between hookworm load, egg counts, and blood losses are difficult to estimate reliably\( ^a \) for a number of reasons. By simply including categories of hookworm eggs/g faeces in our analyses of the species variables, we have compared the iron status of individuals and communities within those categories and thus have likely underestimated the impact of greater blood loss per worm with \( A.\ duodenale \). Although an unbiased estimate of the species difference based on numbers of worms is desirable, any mathematical model would be highly speculative, and this answer awaits a future study in which worms are expelled and counted. In the meantime, it is reasonable to infer that the true effect on iron status by the different species is at least as great as our results would indicate.

We did not measure duration of infection nor iron intake and bioavailability. This does not threaten our inferences unless duration of infection or iron intake were different for children or school communities in different species categories. We can think of no scenario in which the duration of infection might have differed by species, since both species likely have been endemic on Pemba Island for many years and children's risk of exposure with age is not known to differ for the two species. However, this should be associated with poor diet.

The two approaches we took to address the question of species impact have complementary strengths and weaknesses. The comparison of individuals by degree of \( A.\ duodenale \) infection does not associate the species variable with school, an advantage because school communities may vary in level of poverty and thus diet. Rather children are compared to other children, some of whom come from the same school community. Our results from this analysis are also strengthened by the dose-response pattern seen in haemoglobin and ferritin values by degree of \( A.\ duodenale \) infection (Table 3).

The comparison of children grouped by community prevalence of \( A.\ duodenale \) infection represents the practical question that confronts public health planners. Are communities or areas where \( A.\ duodenale \) is highly endemic in greater need of intervention than communities where \( N.\ americanus \) predominates? Based on our results, the answer to this question is 'Yes.' The strength of this analysis is that in reality the risk of \( A.\ duodenale \) infection (or the force of transmission of that parasite) is more characteristic of a community than of an individual. The children in school communities with high prevalence of \( A.\ duodenale \) who happened not to be infected with that species at the time of our survey, have likely experienced \( A.\ duodenale \) in the past or will do so in the future. The community also represents the level at which public health decisions are made. The predominant hookworm species being transmitted may be an appropriate means of characterizing and targeting communities, but will rarely influence the course of treatment of an individual.

Most importantly, the weight of our evidence is strengthened by the consistency of the findings from complementary approaches to the problem. We conclude that, as predicted from earlier clinical studies, the species of hookworm being transmitted in a community influences the burden of iron-deficiency anaemia in the community.

The full implications of hookworm species for the planning and implementation of interventions are yet to be determined. Our results suggest that where iron-deficiency anaemia is a public health problem, hookworm control is particularly urgent if \( A.\ duodenale \) is the predominant species. However, this should not be interpreted to mean that endemic \( N.\ americanus \) infection is of low priority. We and others have demonstrated previously that hookworms can be an important cause of anaemia in populations where \( N.\ americanus \) predominates.\( ^{23,24} \) Where anaemia is prevalent and hookworms are known to be endemic, lack of knowledge about hookworm species should not impede interventions.

A potentially important question is whether the optimal regimen for anthelminthic control of hookworms in populations differs for the two species. Because transmission of \( A.\ duodenale \) has a distinctly seasonal pattern in some environments,\(^ \) it is possible that the efficacy of public health deworming regimens would depend on the seasonal timing of treatments. It is also possible that the rate of reinfection following treatment differs for the two species, with implications for the frequency of treatments. Further epidemiological research is needed to answer these questions.

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Table 5 Iron status of Zanzibari children by prevalence of \( A.\ duodenale \) in the school

<table>
<thead>
<tr>
<th>Iron status indicator</th>
<th>( A.\ duodenale ) prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low, &lt;20% (6 schools, 308 children)</td>
</tr>
<tr>
<td>Haemoglobin (g/dl)</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td></td>
<td>10.5 ± 1.5(^b)</td>
</tr>
<tr>
<td>Protoporphyrin (µmol/mol heme)</td>
<td>Geometric mean 93 (55, 156)(^d)</td>
</tr>
<tr>
<td></td>
<td>% &gt;120</td>
</tr>
<tr>
<td>Ferritin (µg/l)</td>
<td>Geometric mean 14.8 (7.8, 28.0)(^c)</td>
</tr>
<tr>
<td></td>
<td>% &lt;12</td>
</tr>
</tbody>
</table>

\(^a\) Values are predicted from analysis of variance, adjusted for hookworm eggs/g faeces determined by Kato-Katz method, age, height-for-age Z score, malaria parasitaemia, haematuria and sex.

\(^b\) Significantly different from high prevalence schools, \( P < 0.05 \)

\(^c\) Significantly different from high prevalence schools, \( P < 0.10 \)

\(^d\) Significantly different from high prevalence schools, \( P < 0.001 \)
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References


