Trans R Soc Trop Med Hyg 2025; **0**: 1–10
https://doi.org/10.1093/trstmh/traf010 Advance Access publication 0 2025

ORIGINAL ARTICLE

The impact of multiple infections and community knowledge on engagement with a historical deworming programme: hookworm and *Ascaris* in Jamaica, 1913–1936

Jonathan David Roberts [a,b,*], Lorna L. Waddington[b], Rupert J. Quinnell[a], and Alison M. Dunn[a]

[a]*School of Biology, Faculty of Biological Sciences, University of Leeds, Leeds LS2 9JT, UK;* [b]*School of History, Faculty of Arts, Humanities and Cultures, University of Leeds, Leeds LS2 9JT, UK*

*Corresponding author: E-mail: j.d.roberts@leeds.ac.uk

Received 15 April 2024; revised 21 November 2024; editorial decision 15 January 2025; accepted 17 January 2025

Introduction: Community engagement with public health efforts often depends on existing knowledge of a health issue.

Methods: Here, qualitative analysis of archival material from the Jamaica Hookworm Commission (1919–1936) and quantitative analysis of prevalence data are used to assess knowledge of and ecological interactions between different helminths during a historical hookworm eradication campaign.

Results: Archival sources demonstrate that Jamaicans were familiar with *Ascaris lumbricoides.* Surveys revealed a high prevalence of hookworm (62% of individuals infected), *Ascaris* (30%) and *Trichuris trichiura* (32%) in communities targeted for hookworm control. Community prevalence of *Trichuris* was positively associated with the prevalence of *Ascaris* and hookworm. Many individuals were infected with more than one parasite. At an individual level, data from hospital patients and soldiers showed significant associations between all three parasites. The co-occurrence of hookworm and *Ascaris,* alongside folk treatment of *Ascaris* with the same plant used by the Hookworm Commission (*Chenopodium ambrisoides*) to treat hookworm, made biomedical claims about hookworm credible and biomedical treatment more acceptable. Expulsions of *Ascaris* following treatment also provided dramatic proof of the effectiveness of treatment, further facilitating engagement.

Discussion/Conclusion: Knowledge of *Ascaris* and other helminths directly shaped engagement with hookworm treatment, demonstrating how folk medical knowledge, grounded in the biology of the worms, aided a biomedical public health program.

Introduction

Public health efforts rely not only on scientific knowledge, but also on the engagement of individuals and communities.[1–3] Engagement with health programs can depend on individuals' knowledge of a health issue and how far they consider it a threat; likewise they may assess the credibility of claims made by medical practitioners based on what they already know of the illness.[1,4] Adherence to treatment is likewise influenced by knowledge of the relevant treatment or drugs.[5,6] Community knowledge is a product of experience and education in multiple knowledge systems, which may be folk, biomedical or syncretic. This article explores an historical example of folk medical knowledge grounded in experiences of a widespread disease (in this case ascariasis) and its influence on engagement with biomedical health education and treatment targeting a different disease (hookworm).

The early decades of the 20th century saw burgeoning medical awareness of hookworm (*Ancylostoma duodenale* and *Necator americanus*); hookworm control campaigns, often carried out in collaboration between the Rockefeller Foundation (RF) and national, colonial and local governments, were instated across the world during this period.[7–9] We present quantitative analysis of historical data on soil-transmitted helminth infections and qualitative analysis of Jamaican folk knowledge and its effects on the success of the Jamaica Hookworm Commission (JHC, 1919–1936) deworming program. This was a cooperative program between the RF (an independent American philanthropic foundation) and the Jamaican colonial government, spearheaded by the charismatic RF doctor Benjamin Earl Washburn. Washburn's focus on simple, easy-to-implement interventions and gift for public engagement, institution-building and health propaganda have been credited with helping Jamaicans to take control of their own health, leading to sustained gains in life expectancy in a period of widespread poverty and colonial neglect.[10,11] Washburn's focus on health education and interest in the culture of his patients was unusual among medical professionals of his era, contributing to the longevity of the JHC.[10] Hookworm is not a readily visible parasite; it needs to be created in the minds of its hosts before it can be treated, making community knowledge and engagement crucial.[12] Folk medicine was a primary source of treatment for many Jamaicans, particularly among the rural peasantry, as biomedical practitioners were expensive, distant or inaccessible.[13] The peasantry were subsistence farmers occupying small plots of land; their medical knowledge was rooted in a synthesis of African, European, Taíno, South Asian and Chinese traditions.[14]

Currently, Knowledge, Attitudes and Practices surveys are used to assess community knowledge of public health concerns.[15–17] However, these are usually primarily concerned with whether community knowledge is complete and correct by biomedical standards. Here we follow on from literature engaging with the content of community knowledge to consider how this can form aids or obstacles to biomedical public health programs, applying this approach to the past.[18,19]

In this article we aim firstly to assess the prevalence of single and multiple infections with hookworm, *Ascaris* and *Trichuris* in early 20th century Jamaica; secondly to test whether different helminth parasites were associated; thirdly to assess what Jamaicans of this period knew about soil-transmitted helminthiases; and finally to assess how epidemiological associations and knowledge affected attitudes towards hookworm treatment. Our approach has been interdisciplinary, incorporating both historical and parasitological methods. We have used JHC and other records to assess pre-existing Jamaican folk (this term is used following Payne-Jackson and Alleyne[14]) knowledge and treatment of parasitic helminths. We analysed data on the prevalence of hookworm, *Ascaris lumbricoides* and *Trichuris trichiura* from JHC records as well as data on multiple infections derived from both hospital patients and volunteer soldiers. We use these to understand information on folk knowledge and treatment of helminths in light of their prevalence and relationships.

Methods

Data sources

Data from government archives were extracted by searching physical documents from the Colonial Office archives in the UK National Archives (NA; Kew, England) and from the University of the West Indies (UWI) Medical Library (Mona, Jamaica). The main sources were monthly or yearly reports prepared by the JHC, the Island Medical Department and the Government Bacteriological Laboratory. Reports up to 1931 were collected in annual supplements to the *Jamaica Gazette* (NA, file CO/141); reports beyond this date were provided by UWI. Reports forwarded to the Colonial Office and the Colonial Advisory Medical and Sanitary Committee were also used (in NA CO/137 Jamaica: original correspondence). These files report surveys carried out by the JHC across Jamaica and case numbers from the island's public hospitals.

We have used the *Journal of the Jamaica Agricultural Society*, accessed in the Natural History Museum Library (London, England), as a primary source of information on community knowledge and folk medicine. The health education journal *Jamaica Public Health* (1926–1973, published by the Jamaican government in collaboration with the RF) was also used, accessed in the National Library of Jamaica (Kingston, Jamaica). These sources were unindexed and were searched for references to helminth infections on an article-by-article basis.

Parasitology data

District surveys

Pretreatment surveys of hookworm prevalence were carried out by the JHC between 1919 and 1936 using the 'intensive method' of Howard.[20] These aimed to test the entire population of a 'district' of around 500 people for hookworm as part of an 'area' served by a central field office. We used data from 81 districts across 7 areas (in the parishes of Manchester, St Andrew, St Mary, St Catherine and St James) surveyed between 1927 and 1933 in which the prevalence of *Ascaris* and *Trichuris* infection was also reported. Individuals of all ages and genders were tested, but surveys reported only the total number of people tested and infected for each parasite in each district at a single point in time and not how many individuals had multiple infections. Testing used salt flotation and centrifugation of faecal samples.

Hospital data

Data are available on numbers of patients at the 19 Public General Hospitals located in towns across the island tested for helminth infections and the numbers of individuals infected with hookworm, *Ascaris* and *Trichuris* alone or in each possible combination. It was not stated whether individuals were only tested where infection was suspected, nor which method of faecal examination was used; samples were processed by the Government Bacteriological Laboratory and the data reported in the annual medical reports of 1913–1928. Data were sometimes aggregated by hospital and sometimes by month; missing figures and printing errors were encountered, but it was possible to impute the correct value from the totals provided.

Army recruits

Data are also available for tests carried out on 1063 volunteer recruits of the Jamaica Contingent of the British West Indies Regiment (BWIR) prior to embarkation to Britain to join the First World War in 1915 (NA CO/141/79, 'Report of the Island Medical Department', Sup. Jam. Gaz. 39:14 [1916]). They were tested by the Bacteriological Laboratory, who did not specify the testing method used.

No sources used in this article report on burden, hence we only present analysis of prevalence.

Statistical analysis

To test for community-level associations between helminth parasites in the surveyed districts, a generalized least squares model

Table 1. Prevalence of infection with and case numbers of parasitic helminths in Jamaica, 1913–1931. These results include both single and multiple infections. Several species were referred to in these documents by generic names that are no longer used, including *Trichocephalus* for *Trichuris* and *Oxyuris* for *Enterobius*. Here we use the present-day names.

	Prevalence or case numbers				
	Hookworm Commission	Government Bacteriological Laboratory,	British West Indies Regiment	Hospital admissions	
Parasite	Surveys, 1927–1933	1913–1928	Volunteers, 1915	1916	1917
Hookworm	62.1% (n=41 758)	62.7% (n=30 607)	60.1% (n=1 063)	1665 cases (listed under *A. duodenale*)	1192 cases (listed under *A. duodenale*)
Ascaris	30.2% (n=41 758)	34.2% (n=30 607)	27.8% (n=1 063)	273 cases	206 cases
Trichuris (reported as *Trichocephalus*)	32.1% (n=41 758)	37.9% (n=30 607)	33.6% (n=1 063)	–	–
Strongyloides (including data from 31 districts reported under *Strongylus*)	0.193% (n=18 171) reported on in 46 districts	–	–	–	–
Enterobius (reported as *Oxyuris vermicularis*)	0.0111% (n=13 570) reported on in 30 districts	–	–	6 cases	2 cases
'Filarial disease' (term used in original report)	–	–	–	1 case	1 case
'Hookworm disease' (term used in original report)	–	–	–	434 cases	220 cases
Tapeworm (*Taenia*)	'two or three cases' in 1929; 'one case' in 1930	–	–	–	–

(assuming normality; gls from the nlme R package [R Foundation for Statistical Computing, Vienna, Austria]) with an exponential spatial correlation coefficient was fitted to maximize log-likelihood against the logit-transformed prevalence of the first parasite, with only the logit-transformed prevalence of the other species as an explanatory variable. Districts were assigned a point location (latitude–longitude coordinates) based on either historical maps or Google Maps.

The historical maps consulted were located in the David Rumsey Collection (E. Stanford, Jamaica, 1901) and NA CO/137/742, CO/700/JAMAICA37, CO/700/JAMAICA44, CO/1047/513, CO/700/JAMAICA50, CO 700/JAMAICA52, MFQ 1/885, WO/252/1065, WO/78/2424 and WO/78/567.

To test the hypothesis that individuals were co-infected with multiple helminths more often than would occur by chance independent of year, the Cochran–Mantel–Haenszel test was used. Fisher's exact test was used on the subgroup of BWIR recruits.

Results

Prevalence of soil-transmitted helminth infections

Prevalence figures were consistent across data sources (Table 1). Around 6 in 10 Jamaicans (62% in JHC surveys, 63% in laboratory figures and 60% of BWIR volunteers) were infected with hookworm. Neither the JHC nor the Bacteriological Laboratory distinguished between *Ancylostoma* and *Necator* hookworms, reporting 'hookworm' only. Around 3 in 10 Jamaicans were infected with *Ascaris* (30% in JHC surveys, 34% in laboratory figures and 28% of BWIR volunteers). A similar number were infected with *Trichuris* (32% in JHC surveys, 38% in laboratory figures and 34% of BWIR volunteers). These figures (compare Figure 2 below) include both single infections with one parasite and multiple infections with different parasites; individuals with both hookworm and *Ascaris* are included in the percentages for both parasites. Other helminth parasites were recorded infrequently. The JHC reports for 1929 (in NA CO/141/93 Sup. Jam. Gaz. 54:17) and 1933 (UWI) provide prevalence data for the common human parasite *Strongyloides*, while the report for 1925 (NA CO/141/88 Sup. Jam Gaz. 48:7) noted *Strongyloides intestinalis* infection: for this reason we have assumed that the prevalence data reported under a column headed '*Strongylus*' in the 1928 report (NA CO/141/91 Sup. Jam Gaz. 51:5) represents *Strongyloides* infection reported under a spelling error.

Epidemiological associations between hookworm, *Ascaris* and *Trichuris*

At the community level, the prevalence of hookworm infection was positively associated with the prevalence of *Trichuris*

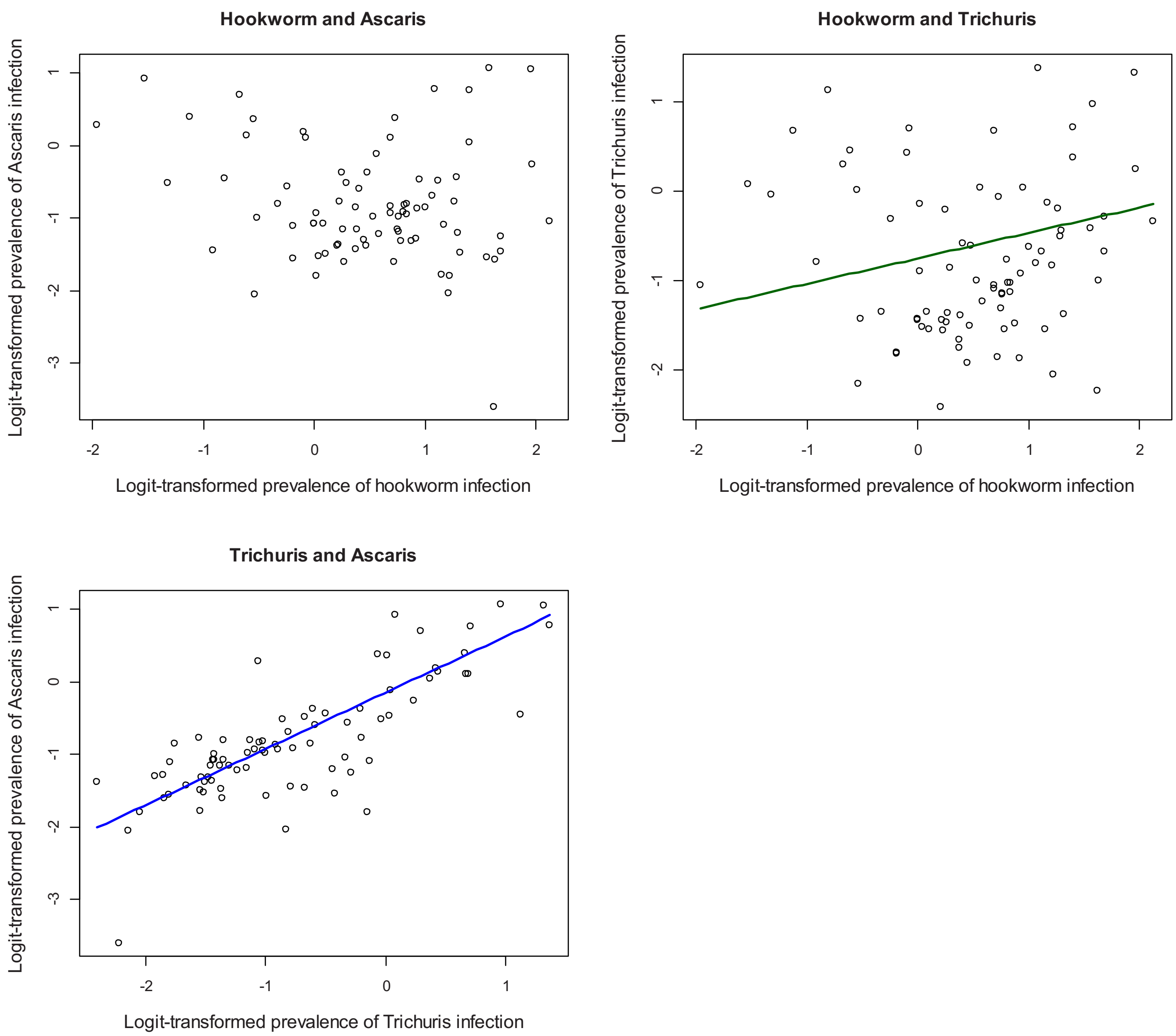

Figure 1. Logit-transformed prevalence of hookworm, *Ascaris* and *Trichuris* infections in 81 districts of Jamaica plotted against each other, 1927–1933. Lines show Loess smoothing of model predictions for each district.

infection (t=2.56, p=0.0124) but not *Ascaris* infection (t=0.965, p=0.337; Figure 1). However, the prevalence of *Ascaris* infection was associated with the prevalence of *Trichuris* infection (t=12.1, p<0.0001; Figure 1).

To test for associations at an individual level, data from Jamaica's Government Bacteriological Laboratory were used. These gave the numbers of individuals testing positive for *Ascaris, Trichuris* and hookworm alone and in each possible combination (Figure 2). Hookworm, *Ascaris* and *Trichuris* were associated on an individual level (Table 2). Hookworm was associated with both *Ascaris* and *Trichuris*, but the latter two parasites were even more closely associated with each other.

Infections among BWIR volunteers (Table 2, Figure 3) show a similar pattern to that among hospital patients (Figure 2). In the volunteers, hookworm infection was similarly positively associated with *Ascaris* and *Trichuris* infection; *Ascaris* and *Trichuris* were also positively associated (Table 2).

Community knowledge of helminths and anthelmintics

Hookworm, *Ascaris* and *Trichuris* were widespread in early 20th century Jamaica. However, medical attention focused on hookworm, which was seen as one of the principal threats to public health, alongside malaria and tuberculosis.[10] Hookworm features frequently in government reports, health education literature and occasionally in the *Journal of the Jamaica Agricultural Society (JJAS)*. References to other helminths are harder to find: between 1926 and 1936, *Jamaica Public Health* published only one article focusing on 'roundworms' (*Ascaris*). Five articles in *JJAS*, discussed below, referred to medicinal plants effective against

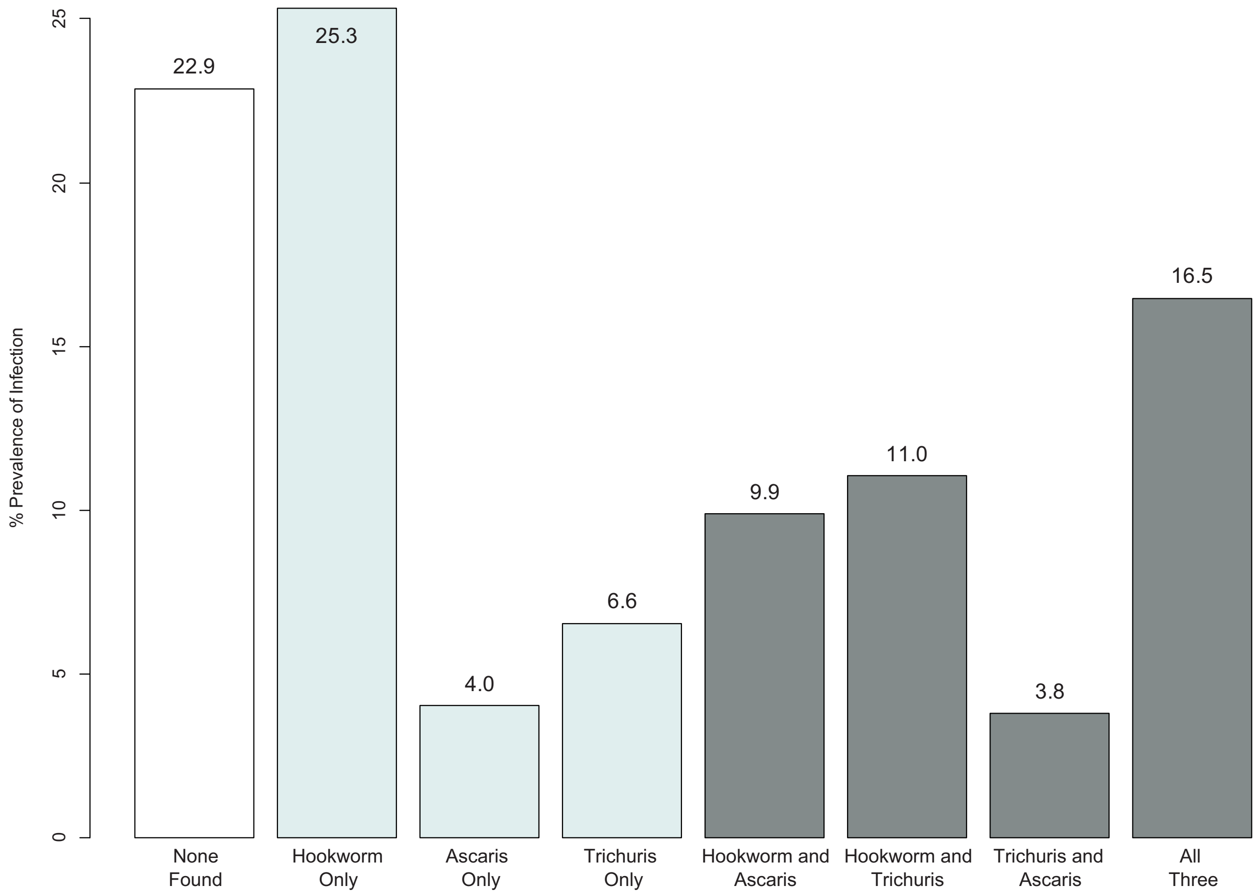

Figure 2. Percentages of 30 607 people found infected with soil-transmitted helminth infections in Jamaican Public General Hospitals, 1913–1928. Data from NA CO/141/78-92, Annual Medical Reports, Sup. Jam. Gaz. 36:18–52 (1913–1929).

hookworm and provide useful information about knowledge of other helminths. While the JHC reported the numbers of cases of other helminthiases, they seldom provided any qualitative information about these.

Four themes were identified in this literature: (1) early 20th century Jamaicans were familiar with parasitic helminths, principally *Ascaris*. This lent credibility to JHC assertions about hookworm, which was less familiar. (2) Medicinal plants, including *Chenopodium ambrisoides* (known in Jamaica as semi-contract), were used to treat these worms. This helped make the use of chenopodium oil as an anthelmintic by the JHC acceptable (here we use chenopodium to refer to the anthelmintic drug and *C. ambrisoides* to refer to the plant). (3) The large, well-known and highly visible *Ascaris*, when expelled by treatment with chenopodium, provided dramatic and visible proof of the effectiveness of JHC medication. (4) This was sometimes used by the JHC to promote hookworm treatment.

Familiarity with Ascaris and other helminths

Jamaicans were sufficiently familiar with *Ascaris* to have given it at least two common names and understood it to affect the gastrointestinal tract, as shown in a 1928 *Jamaica Public Health* article titled 'Roundworms':

> The scientific name of the worm is Ascaris lumbricoides, but in Jamaica it is commonly known as the "stomach" or "greedy" worm. (*Jamaica Public Health* 3:12 [December 1928], pp. 5–6)

Familiarity with helminth parasites of livestock and their treatment is also evident. As early as 1915, *JJAS* advertised the usefulness of tansy (*Tanacetum vulgare*) against 'the dreaded Hook Worm', noting that 'Tansy tea has always been locally used as a specific for worms in horses', though apparently previously not in humans (*JJAS* 19 [1915], p. 402). While hookworm was by this point worrying medical authorities, no evidence was encountered that either hookworm or *Trichuris* were specifically known or distinguished from other intestinal worms by folk medicine the way *Ascaris* was, though they may have been recognized within a general category of 'worms'.

Table 2. Associations between infection with hookworm, *Ascaris* and *Trichuris* in faecal samples from Jamaican Public General Hospitals and BWIR volunteers tested by the Jamaican National Bacteriological Laboratory.

Group	OR: hookworm infection as a risk factor for *Ascaris* infection	95% CI	OR: hookworm infection as a risk factor for *Trichuris* infection	95% CI	OR: *Ascaris* infection as a risk factor for *Trichuris* infection	95% CI
Hospital patients	2.24 ($p<2.2\times10^{-16}$)	2.12 to 2.37	2.00 ($p<2.2\times10^{-16}$)	1.90 to 2.10	7.22 ($p<2.2\times10^{-16}$)	6.88 to 7.59
BWIR soldiers	3.18 ($p=1.50\times10^{-14}$)	2.33 to 4.35	2.02 ($p=3.09\times10^{-7}$)	1.54 to 2.65	2.12 ($p=1.54\times10^{-7}$)	1.60 to 2.79

OR: odds ratio; CI; confidence interval.
Cochran–Mantel–Haenszel test used for hospital patients and Fisher's exact test used for BWIR volunteers. Data from NA CO/141/78-92, Annual Medical Reports, Sup. Jam. Gaz. 36:18–52 (1913–1929).

Folk usage of C. ambrisoides

C. ambrisoides was widely used as an anthelmintic in early 20th-century Jamaican folk medicine. *JJAS* reported:

> With reference to our paragraph in the October JOURNAL that a strong infusion of Tansy has been found to be useful in eradicating Hook Worm, a medical man writes that a decoction of Bitterwood is better, but the plant called locally Wormweed (*chenopodium* [sic] *ambrisoides*) promises to be the best remedy of all; better even than Thymol...Wormweed is commonly known and used for ordinary intestinal worms. (*JJAS* 19 [1915], p. 477)

In 1924, *JJAS* reported that *C. ambrisoides*

> has long been used as a "bush tea" by wise old women...We know of a case where a family running with their barefeet, – as most children do when at home, – but getting a dose of this particular bush tea every Saturday, were, on test, found to be free of the pest [hookworm], whereas the father who always wore boots and who never bothered about "bush tea" was found highly infested. (*JJAS* 28/9 [1924] p. 320)

The *JJAS* returned to their advocacy of bush tea in 1926 on the grounds that weekly use of 'such homeopathic doses prevented infection of Hookworm' (*JJAS* 30/3 [1926], p. 84). They had previously, in the 1924 article discussed above, urged their readers to

> Get some Chenopodium or Semi-contract in a corner of your garden along with other herbs, like Mint. We can supply seed. (*JJAS* 28/9 [1924], p. 320).

The enthusiasm of the Jamaica Agricultural Society for *C. ambrisoides* was based not only on its endorsement by biomedicine, but also on its status as a widespread, effective and time-honoured folk remedy.

Expulsion of Ascaris demonstrated anthelmintic effectiveness

The dramatic effect of chenopodium on *Ascaris* provided a valuable advertisement for hookworm treatment. The medical report for 1929 remarks that

> These [*Ascaris, Trichuris* and *Enterobius*] and two or three cases of tape-worm infection, have responded well to the Chenopodium and Thymol, the efficiency of which is often judged by the native from the number of "greedy" worms (ascaris) expelled. (NA CO/141/93 'Annual Medical and Sanitary Report for the Year 1929', Sup. Jam. Gaz. 53:2 [17 April 1930])

This anecdote is presented as a curiosity, but it is more useful to see it as an entirely sensible metric of anthelmintic action. *Ascaris* (150–350 mm long) are much larger than hookworms (7–13 mm) and consequently far easier to see when expelled.[21,22] This report also demonstrates that many Jamaicans knew *Ascaris* to be a threat to their health and took the opportunity offered by the JHC to remove it.

On the other side of the Caribbean in St Lucia, Dr Stanley Branch similarly noted that chenopodium's 'efficacy as a lumbricoid expellant has I think helped to persuade' patients to take treatment (Rockefeller Archive Center, RG 5/3.457H/190/2344 St. Lucia—Hookworm, Quarterly, Semi-annual and Annual Reports, 1917). 'Lumbricoid' refers to *Ascaris lumbricoides*.

Use of Ascaris to promote health efforts

The JHC eventually recognized that *Ascaris* could be used to promote hookworm treatment. *Jamaica Public Health* regularly featured, alongside instructional articles and health advice, stories penned by Washburn in which his child protagonists learned to 'keep well' and instructed their parents in what they learned.[10] In one of these, published in 1930, folk healer Aunt Eliza was only persuaded to take hookworm medication (which she notes 'smell like semi-contrac' tea') after Mrs Francis reports that, post-treatment,

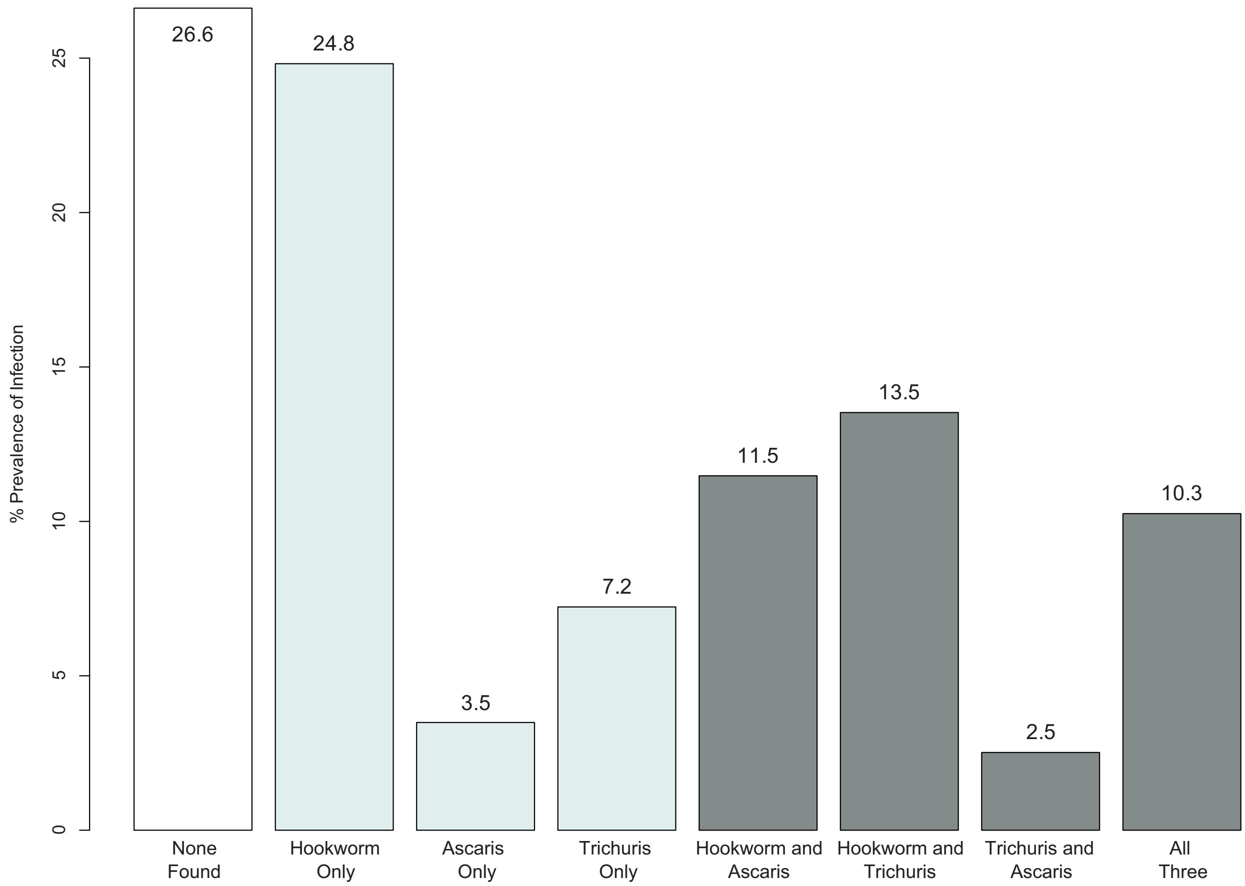

Figure 3. Percentages of 1063 Jamaican volunteer soldiers of the BWIR found infected with soil-transmitted helminth infections, 1915. Data from NA CO/141/79 'Report of the Island Medical Department', Sup. Jam. Gaz. 39:14 (7 September 1916).

> My daughter, Retinella, is passing, such big, tall, round worms and they are all alive. It must be good for her and I am glad that the dispenser has come here and truly glad for the medicine. (*Jamaica Public Health* 5 [1930], pp. 30–31)

Following this, Aunt Eliza, 'swallowing her medicine', says 'me wan fi see de worms' [I want to see the worms], concluding that 'Di hookworm medicine fi good' [the hookworm medicine is a good thing]. This is an idealized account authored by a propagandist, but it shows that Washburn recognized that the spectacle of *Ascaris* expulsion could be a valuable advertisement for hookworm medicine and a means to persuade reluctant patients of its efficacy.

Discussion

Co-infections

Ascaris, Trichuris and hookworm were all prevalent in this period, with other intestinal parasites being recorded less frequently. However, these data, being based on faecal examinations, likely underestimate the prevalence of *Strongyloides* and *Enterobius* (pinworm).[23,24] Those infected with hookworm were around twice as likely to be infected with either *Trichuris* or *Ascaris* as those without any parasite infections. *Ascaris* and *Trichuris* were even more closely associated: infection with *Ascaris* or *Trichuris* was associated with a sevenfold increase in the risk of infection with the other parasite in hospital patients and a twofold increase among BWIR volunteers. Similar prevalences of both single and multiple infections and comparable odds ratios were obtained for both hospital patients and BWIR volunteers, who were required to be healthy adult men, mostly in their 20s.[25,26] This suggests that the three helminths were associated regardless of the health of the host.

Positive associations between hookworm and other parasites, including *Ascaris* and *Trichuris*, are commonly reported.[27–30] *Ascaris, Trichuris* and hookworm share similar modes of transmission in that their transmission phase is found in soil that has been contaminated with human faeces. This results in overlapping risk factors: all three are positively associated with warmer, wetter and more vegetated areas and negatively associated with improved sanitation.[31–36] Identical modes of transmission and very similar age-prevalence profiles result in *Ascaris* and *Trichuris* being strongly associated and commonly found together.[22] Likewise, individuals who are immunologically vulnerable to one helminth can also be expected to be vulnerable to others. It is also likely that immunomodulation of the host immune response plays a role in the positive associations between these helminth parasites.[22] Hookworms in particular downregulate host production of a variety of immunoproteins and lymphocytes while upregulating T cell apoptosis and T regulatory cell populations, while *Ascaris* and *Trichuris* are known to block dendritic cell function, thereby reducing T cell activity.[37–39] However, the particularly strong association in this study and others between *Ascaris* and *Trichuris* suggests that faecal–oral transmission, rather than immunomodulation, may be of primary importance in co-infections.

Knowledge of helminths

We have shown that familiarity with *Ascaris* and other intestinal parasitic helminths of humans and livestock lent credibility to claims about hookworm: the *JJAS* encouraged its readers to use herbal treatments for hookworm (tansy and *C. ambrisoides*) on the basis of their pre-existing use as a treatment for other helminths. Use of *C. ambrisoides* to treat *Ascaris* and other 'ordinary intestinal worms' was widespread. The expulsion of *Ascaris* similarly provided vivid visual proof of the effectiveness of chenopodium oil and other drugs used by the JHC.

The *JJAS* reported folk usage of *C. ambrisoides* as an anthelmintic in Jamaica between 1915 and 1926, with the implication that this was long-standing. Use of *C. ambrisoides* to treat pinworm in children in Central American folk medicine during this period is reported by Palmer,[40] while its use as a vermifuge has likewise been reported in present-day Jamaican folk medicine by Payne-Jackson and Alleyne.[14] The RF and colonial authorities were primarily concerned with hookworm, but ordinary Jamaicans used the hookworm campaign to improve their own health outside of the bounds set by the colonial government; they saw *Ascaris* as a threat to their health and took the opportunity presented by the hookworm campaign to remove it, as demonstrated by positive responses to *Ascaris* expulsion. The framing of *Ascaris* as 'greedy' further underlines that Jamaicans understood that *Ascaris* was devouring the food they had eaten and thereby depriving them of nourishment. Hookworm was not the only worm they cared about.

Ascaris expulsion following treatment also functioned as 'theatre of proof' for the JHC, dramatically demonstrating the effectiveness of their medicine.[41] Palmer,[40,42] in his study of Guatemala, Nicaragua, Costa Rica, Panama, British Guiana (Guyana) and Trinidad and Tobago claims that chenopodium's dramatic effects on *Ascaris* made it favoured over other drugs by RF doctors, suggesting a similar use of *Ascaris* elsewhere in the circum-Caribbean to that which we have shown here.

Existing knowledge of *Ascaris* similarly made biomedical claims about another dangerous intestinal worm (hookworm) credible. Hookworms are not readily visible to their host; people infected with them, even where symptoms were acute, often had no idea of their presence, especially as their primary symptom (anaemia) is neither distinctive nor obviously related to the digestive system. The existence of hookworms is not self-evident.[12] In contrast, the larger and more migratory *Ascaris* was far more visible and familiar to Jamaicans, who already regarded it as a medical threat requiring treatment. While hookworm was unfamiliar, the knowledge that intestinal worms caused illness was widespread.

Noting that notions of worms causing illness are near-universal across medical knowledge systems, Palmer[42] has argued that RF doctors were able to use this non-biomedical knowledge to promote their own epistemologies of hookworms causing disease. This 'worm theory' created an epistemic middle ground facilitating exchanges of medical knowledge. Payne-Jackson and Alleyne[14] have shown that worms are directly linked to stomach problems in present-day Jamaican folk medical epistemologies; here we have shown widespread knowledge of the dangers of *Ascaris* and other 'ordinary intestinal worms' in the early 20th century. Palmer's discussion of 'worm theory' accords well with our results, as well as with Stuart's[43] account of RF doctor Sylvester Lambert's encounter with a Papuan medical knowledge system that blamed worms in the belly for illness—which for Lambert highlighted the uncomfortable similarities between himself and those he viewed as 'witch-doctors'. We go beyond Palmer in showing that this extended to treatment: just as familiarity with *Ascaris* made hookworm programs credible, familiarity with *C. ambrisoides* made treatment with chenopodium oil acceptable. Furthermore, we show that 'worm theory' was underpinned by the ecological relationships between worms: the fact that *Ascaris* was widespread, familiar and positively associated with hookworm enabled Washburn and the JHC to use it to promote 'worm theory'. Many of those whom the JHC had to persuade to take treatment for hookworm were already familiar with, and often also infected with, *Ascaris*. Had *Ascaris* been less widespread, or not associated with hookworm, the JHC's task might have been significantly more difficult.

Conclusions

Hookworm, *Ascaris* and *Trichuris* were widespread across early 20th century Jamaica, and *Ascaris* was familiar to Jamaicans as the 'stomach' or 'greedy worm'. Those infected with one of these parasites were at increased risk of infection with another; around as many Jamaicans were infected with both hookworm and the more visible and familiar *Ascaris* (26.4%; Figure 2) as were infected with hookworm alone (25.3%; Figure 2) while far fewer were infected with Ascaris but not hookworm (7.8%, Figure 2). Familiarity with *Ascaris* lent credibility to JHC claims about hookworm, as did pre-existing folk usage of one of the same anthelmintics used by the JHC (*C. ambrisoides*). Simultaneously, expulsion of *Ascaris* provided further proof of the effectiveness of JHC medication, helping to drive public engagement with hookworm treatment. Ecological relationships existed between hookworm, *Ascaris* and *Trichuris*, as the three species commonly co-occurred and co-infected people. This enabled an epistemic relationship to emerge, as knowledge of *Ascaris* and other helminths shaped knowledge of hookworm. This epistemic relationship was exploited by public health workers concerned with hookworm. Knowledge of *Ascaris,* known to be a threat to health and treated with *C. ambrisoides,* helped persuade Jamaicans to engage with the JHC and also persuaded them of the effectiveness of JHC treatment; folk medical knowledge can be a valuable aid to biomedical health education. It can be useful for medical and public health workers to engage with how folk knowledge can aid health programs, as researchers in the present are already doing.[19,44]

Authors' contributions: JDR, AMD, LW and RJQ were responsible for the conceptualization and investigation and reviewing, critiquing and editing the manuscript. JDR, RJQ and AMD were responsible for the statistical design. JDR was responsible for archival research, data collection and curation and writing the original draft.

Acknowledgements: This research was made possible by the generous assistance of many people, including John Lindo, Tereza Richards and the Medical Library staff at the University of the West Indies; Margaret Williams Pryce and the staff of the Jamaica Archives; John Grahame; Elen Simpson and the archive staff at Bangor University; the staff at the National Library of Jamaica and the staff of the UK National Archives. We would also like to thank the senior common room at Mona Campus, UWI for the warm welcome and all the friendly assistance they gave Jon in Jamaica, and Darcy Heuring and Henrice Altink for the assistance they gave Jon in planning his trip.

Funding: This research was funded by the Leverhulme Trust as part of the Extinction Studies Doctoral Training Programme at the University of Leeds.

Competing interests: We confirm that we have no competing interests to declare.

Ethical approval: Not required.

Data availability: Data are available upon request. The datasets were derived from public records held in the UK National Archives (Kew) and the University of the West Indies Medical Library.

References

1 Shumaker SA, Ockene JK, Riekert KA. The handbook of health behaviour change. New York: Springer; 2008.

2 Sedekia Y, Kapiga S, Mcharo O, et al. Does a school-based intervention to engage parents change opportunity for handwashing with soap at home? Practical experience from the Mikono Safi trial in Northwestern Tanzania. PLoS Negl Trop Dis. 2022;16(6):e0010438.

3 Bartlett AW, Mendes EP, Dahmash L, et al. Knowledge, attitudes, practices and acceptability of a school preventive chemotherapy programme for schistosomiasis and soil-transmitted helminths control in Angola. Philos Trans R Soc Lond B Biol Sci. 2023;378(1887):20220430.

4 Akenji TKN, Ntonifor NN, Ching JK, et al. Evaluating a malaria intervention strategy using knowledge, practices and coverage surveys in rural Bolifamba, southwest Cameroon. Trans R Soc Trop Med Hyg. 2005;99(5):325–32.

5 Cambaco O, Menendez YA, Kinsman J, et al. Community knowledge and practices regarding antibiotic use in rural Mozambique: where is the starting point for prevention of antibiotic resistance? BMC Public Health. 2020;20:1183.

6 Ghimire S, Castelino RL, Jose MD, et al. Medication adherence perspectives in haemodialysis patients: a qualitative study. BMC Nephrol. 2017;18:167.

7 Pemberton R. A different intervention: the International Health Commission/Board, Health, Sanitation in the British Caribbean, 1914–1930. Carib Q. 2003;49(4):87–103.

8 Farley J. To cast out disease: a history of the International Health Division of the Rockefeller Foundation (1913–1951). Oxford: Oxford University Press; 2004.

9 Kavadi SN. 'Parasites lost and parasites regained': Rockefeller Foundation's anti-hookworm campaign in Madras presidency. Econ Polit Wkly. 2007;42(2):130–7.

10 Jones M. Public health in Jamaica, 1850–1940: neglect, philanthropy and development. Kingston: University of the West Indies; 2013.

11 Riley JC. Poverty and life expectancy: the Jamaica paradox. Cambridge: Cambridge University Press; 2005.

12 Ettling J. The germ of laziness: Rockefeller philanthropy and public health in the new south. London: Harvard University Press; 1981.

13 Heuring DH. Health and the politics of 'improvement' in British Colonial Jamaica, 1914–1945. PhD dissertation, Northwestern University, Evanston, IL; 2011.

14 Payne-Jackson A, Alleyne MC. Jamaican folk medicine: a source of healing. Kingston: University of the West Indies Press; 2004.

15 Sánchez-Marqués R, Salvador F, Bocanegra C., et al. *Schistosoma haematobium* infection and morbidity risk factors for pre-school age children in western Angola: a knowledge, attitudes and practices survey. PLoS Negl Trop Dis. 2023;17(10):e0011650.

16 Essien-Baidoo S, Essuman MA, Adarkwa-Yiadom B, et al. Urinogenital schistosomiasis knowledge, attitude, practices, and its clinical correlates among communities along water bodies in the Kwahu Afram Plains North District, Ghana. PLoS Negl Trop Dis. 2023;17(8): 30011513.

17 Zacharia F, Silvestri V, Mushi V, et al. Burden and factors associated with ongoing transmission of soil-transmitted helminths infections among the adult population: a community-based cross-sectional survey in Muleba district, Tanzania. PLoS One. 2023;18(7):e0288936.

18 Brieger WR, Kendall C. Learning from local knowledge to improve disease surveillance: perceptions of the guinea worm illness experience. Health Educ Res. 1992;7(4):471–85.

19 Akinsolu FT, Abodunrin OR, Olagunju MT, et al. Community perception of school-based mass drug administration program for soil-transmitted helminths and schistosomiasis in Ogun State, Nigeria. PLoS Negl Trop Dis. 2023;17(7):e0011213.

20 Howard HH. The control of hookworm disease by the intensive method. New York: Rockefeller Foundation; 1919.

21 Centers for Disease Control. Ascariasis. https://www.cdc.gov/sth/about/ascariasis.html [accessed 14 October 2023].

22 Brooker S, Bethony J, Hotez PJ. Human hookworm infection in the 21st century. Adv Parasitol. 2004;58:197–288.

23 Ketzis JK, Conan A. Estimating occurrence of *Strongyloides stercoralis* in the Caribbean island countries: implications for monitoring and control. Acta Trop. 2017;171:90–5.

24 Amor A, Rodriguez E, Saugar JM, et al. High prevalence of *Strongyloides stercoralis* in school-aged children in a rural highland of north-western Ethiopia: the role of intensive diagnostic work-up. Parasit Vectors. 2016;9(1):617.

25 Howe G. Race, war and nationalism: a social history of West Indians in the First World War. Kingston: Ian Randle; 2002.

26 Smith R. Jamaican volunteers in the First World War: race, masculinity and the development of national consciousness. Manchester: Manchester University Press; 2004.

27 Sayasone S, Mak TK, Vanmany M, et al. Helminth and intestinal protozoa infections, multiparasitism and risk factors in Champasack Province, Lao People's Democratic Republic. PLoS Negl Trop Dis. 2011;5(4):e1037.

28 Sayasone S, Urtzinger J, Akkhavong K, et al. Multiparasitism and intensity of helminth infections in relation to symptoms and nutritional status among children: a cross-sectional study in southern Lao People's Democratic Republic. Acta Trop. 2015;2015:322–31.

29 Loukas A, Hotez PJ, Diemert D, et al. Hookworm infection. Nat Rev Dis Primers. 2016;2:16088.

30 Bradbury RS, Harrington H, Kekeubata E, et al. High prevalence of ascariasis on two coral atolls in the Solomon Islands. Trans R Soc Trop Med Hyg. 2018;112(4):193–9.

31 Addisu A, Zeleke AJ, Bayih AG, et al. Trends and seasonal patterns in intestinal parasites diagnosed in primary health facilities in Northwest Ethiopia. J Infect Dev Ctries. 2020;14(6.1):58S–65S.

32 Ajjampur SSR, Kaliappan SP, Halliday KE, et al. Epidemiology of soil transmitted helminths and risk analysis of hookworm infections in the community: results from the DeWorm3 Trial in southern India. PLoS Negl Trop Dis. 2021;15(4):e0009338.

33 Chaiyos J, Suwannatrai K, Thinkhamrop K, et al. MaxEnt modeling of soil-transmitted helminth infection distributions in Thailand. Parasitol Res. 2018;117(11):3507–17.

34 Strunz EC, Addiss DG, Stock ME, et al. Water, sanitation, hygiene, and soil-transmitted helminth infection. PLoS Med. 2014;11(3):e1001620.

35 Okoyo C, Campbell SJ, Owaga C, et al. Statistical regression model of water, sanitation, and hygiene; treatment coverage; and environmental influences on school-level soil-transmitted helminths and schistosome prevalence in Kenya: secondary analysis of the National Deworming Program data. Am J Trop Med Hyg. 2021;104(6):2251–63.

36 Chopra P, Shekhar S, Dagar VK, et al. Prevalence and risk factors of soil-transmitted helminthic infections in the pediatric population in India: a systematic review and meta-analysis. J Lab Phys. 2022;15(1):4–19.

37 Shalash AO, Hussein WM, Skwarczynski M, et al. Hookworm infection: toward development of safe and effective peptide vaccines. J Allergy Clin Immunol. 2021;148(6):1394–419.e6.

38 Phasuk N, Apiwattanakul N, Punsawad C. Profiles of $CD4^+$, $CD8^+$, and regulatory T cells and circulating cytokines in hookworm-infected children in southern Thailand. Med Microbiol Immunol. 2022;211(1):19–28.

39 Loukas A, Maizels RM, Hotez PJ. The yin and yang of human soil-transmitted helminth infections. Int J Parasitol. 2021;51(13–14):1243–53.

40 Palmer SP. Toward responsibility in international health: death following treatment in Rockefeller hookworm campaigns, 1914–1934. Med Hist. 2010;54(2):149–70.

41 Stein EA. Colonial theatres of proof: representation and laughter in 1930s Rockefeller Foundation hygiene cinema in Java. Health Hist. 2006;8(2):14–44.

42 Palmer SP. Launching global health: the Caribbean odyssey of the Rockefeller Foundation. Ann Arbor: University of Michigan Press: 2010.

43 Stuart A. We are all hybrid here: the Rockefeller Foundation, Sylvester Lambert, and health work in the colonial South Pacific. Health Hist. 2006;8(1):56–79.

44 Rwamwejo F, Ndatinya GI, Mkata MI, et al. Assessing the knowledge, attitudes, practices, and perspectives of stakeholders of the deworming program in rural Rwanda. PLoS Negl Trop Dis. 2023;17(8):e0010759.