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A comparative study of intestinal helminths in pre-school-age urban and rural children in Morobe Province, Papua New Guinea

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SUMMARY

Children aged between 1 month and 10 years from one rural coastal locality, two rural upland localities and two urban localities in Morobe Province, Papua New Guinea were examined between September 1980 and September 1982. Hookworm (predominantly *Necator americanus*), *Ascaris lumbricoides* and *Trichuris trichiura* increased in prevalence with age. The prevalence of *Strongyloides fuelleborni* subspecies *kellyi*, where present, was either highest in the <1 year age group or similar in all age groups. *N. americanus* prevalence was between 59% and 83% in the 3 year age group except at the coastal locality, where it was 15%. *A. lumbricoides* prevalence in the 3 year age group was very low in one upland locality and between 7% and 41% for the other localities. *T. trichiura* prevalence in the 3 year age group was between 33% and 55% at the coastal and two urban localities, and very low at the two upland localities. *S. f. kellyi* prevalence in the <1 year age group was 48% and 20% respectively at the two upland localities, 2% at one of the urban localities and not detected at the other localities. *Strongyloides stercoralis* was detected at both urban localities, but not at the coastal locality or at the upland locality where testing was done. Many children had infections of more than one species, and there was a significant association of *A. lumbricoides* with *T. trichiura* at the coastal and two urban localities. The presence of *S. f. kellyi* at one of the urban localities raises the possibility that this once isolated species may now be spreading as infected people visit and settle in the towns. Between 68% and 93% of children in the 3 year age group and between 65% and 100% in the 5 year age group were infected with at least one helminth species.

Introduction

Intestinal helminths, predominantly *Necator americanus, Ascaris lumbricoides* and *Trichuris trichiura* are endemic throughout Papua New Guinea (1,2). In addition, *Strongyloides fuelleborni* subspecies *kellyi* is prevalent but with a restricted distribution (3). In recent years, there has been a growing awareness throughout the world of the public health significance of these parasitic diseases, particularly their detrimental effect on child development.

There is increasing evidence that chronic infection with helminth parasites, including *N. americanus*, *A. lumbricoides* and *T. trichiura,* at levels that do not cause acute disease, are a major factor in malnutrition, decreased fitness and decreased cognitive ability. Stephenson (4) has summarized the mechanisms involved. These parasites cause blood loss or malabsorption of nutrients, leading to iron deficiency anaemia, which is associated with decreased appetite, growth rate, activity, fitness, work capacity, cognitive ability, school performance and productivity. Even when

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anaemia is not present, intestinal helminths, particularly *Trichuris trichiura* infections, lead to an increase in the inflammatory cytokine tumor necrosis factor-α (TNF-α) in children, causing decreased appetite and consequently decreased food intake (5,6). Intestinal helminths have also been implicated in reduced efficacy of BCG vaccination (7) and *Salmonella* and influenza vaccination (8).

Heavy burdens of helminth parasites cause acute disease. It has long been known that hookworms are a major cause of iron deficiency anaemia (9,10), and this is life threatening when the hookworm load is high and the person is iron deficient. *Ascaris lumbricoides* causes blockage of the gut in young children when infected with more than 60 worms (11) and this is also life threatening. *Trichuris* dysentery syndrome (TDS), comprising chronic dysentery, anaemia, rectal prolapse and clubbing of the fingers, is associated with egg counts of more than 30,000 per g of stool (6,12). *Strongyloides fuelleborni kellyi* in high numbers causes swollen belly syndrome in babies, particularly in damp climates, and this is fatal if not treated with appropriate anthelmintic drugs (3,13). *Strongyloides stercoralis* is a life-long disease if not eradicated from the body, because the parasites multiply in the host through a process of autoinfection (14,15). Immune impairment and other unknown factors allow the worms to multiply out of control (hyperinfective or severe complicated strongyloidiasis) and overwhelm the host if the underlying cause is not treated effectively (16,17).

In this study, the abundance and distribution of intestinal parasites in pre-school-age children was investigated as part of a series of nutrition surveys in Morobe Province, Papua New Guinea (PNG) which took place between September 1980 and September 1982 (18-23). Although these data were collected in the 1980s, they provide important baseline information with which to compare the present epidemiology of intestinal helminths in young children, given that the current standard treatment for children in PNG includes the anthelmintic drug albendazole (24).

Methods

The parasitological survey was carried out in conjunction with a comparative study of nutritional status of pre-school-age children in Morobe Province. At Aseki, the nutrition study was part of a road impact study. Subjects were children aged between 1 month and 10 years who were brought to the survey point by a parent or guardian. This was considered to be a representative sampling method without bias, because at the time the mothers used to bring their children, both well and unwell, to the Maternal and Child Health (MCH) clinic regularly on the appointed day for check-ups. The surveys in this study were carried out as part of that MCH process. Most of the children were 5 years old or younger. The children surveyed were from three areas, Wasu (rural coastal), Aseki (rural uplands) and Lae (urban) (Figure 1).

Survey locations and date of study

Wasu – on the north coast of Morobe Province, November 1980 (rural coastal): the children were surveyed at Lambutina Health Centre and were from 5 villages along the coastline and 2 villages about 10 km from the coast (Figure 2). The sea was frequently used for disposal of waste in the coastal villages. Some villages were near Sio Lagoon, and had some coastal swampy land nearby. Fresh water was 20 minutes' to 1 hour's walk away, or from wells near Sio Lagoon for the villages adjoining the lagoon. The MCH clinic and health centre was about 20 km away from the furthest village, accessible by foot or canoe.

Aseki 1 – June to September 1981 (rural uplands): villages surveyed were from 1200 to 1800 m above sea level. About one-third of the villages were connected by road (Figure 3), the rest by walking track only. Survey work was carried out at Angewanga village (June), Hoganeiwa and Kamiagaga villages (July) and Aseki Rural Health Centre (September) and included children from 15 villages within walking distance of the survey points. Water was obtained from springs, or from rainwater tanks at Aseki station.

Aseki 2 (*Langemar*) – May 1981 (rural uplands): Langemar airstrip and the adjoining Otete aid post are about 1500 m above sea level (Figure 3) and are not accessible by road. The children surveyed came to the aid post from 4 villages that were within walking distance. Fresh water was obtained from a spring, a few minutes' walk away, in the wet season, and from the river, one hour's walk away, in the dry season.

Buimo Road Settlement, *Lae* – September

Figure 1. Morobe Province showing the study areas: Wasu (coastal), Lae (urban: Buimo Road Settlement and Taraka) and Aseki (upland – Aseki villages surveyed were accessible by road or from Langemar airstrip).

Figure 2. Wasu coastal study area, showing the location of the coastal and inland villages surveyed.

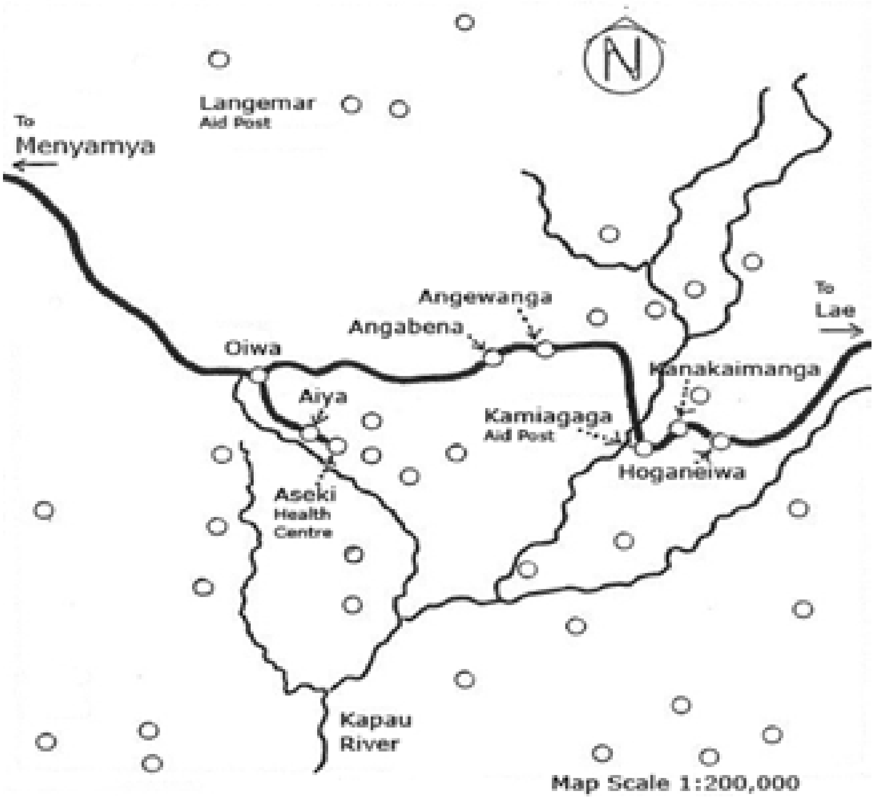

Figure 3. Aseki study area showing Aseki villages accessible by road and the Langemar villages accessible from the airstrip.

1980 (urban): the settlement is situated on the southern bank of the Bumbu River about 5 km from the coast (Figure 4). This settlement included people who had migrated from both coastal and inland areas. The survey took place at the MCH centre. Housing was of the privately owned 'self-help' type, and about two-thirds were considered by the Town Planner to be deteriorating or dilapidated. Sanitation was by pit latrine. Water was obtained from rainwater tanks or the Bumbu River. The hospital and MCH centre were 4 km away.

Taraka, *Lae* – June 1981 (urban): Taraka is a suburb located on both sides of the Bumbu River about 4 km upstream from Buimo Road Settlement (Figure 4). The survey took place at the MCH clinic located within the suburb. Housing was a mixture of government low-covenant rental housing (37%) and privately owned 'self-help' type (25). 32% of houses were deteriorating or dilapidated, according to the Town Planner. Each house was provided with a pit latrine, and each plot was provided with reticulated water to an outside tap (25).

Parasitology

The mother or guardian of each child was given a sterile, labelled plastic jar with identifying marks if there was more than one child in the family, and instructed about how to collect the stool and how much to collect. The stools were returned as soon as possible after collection (usually the next day) and refrigerated as soon as possible. All stools were examined in the laboratory by the Macmaster counting chamber technique (26), except for 5 stools from Taraka and 2 from Aseki that were too small for a Macmaster count and were examined by weighed direct smear only. Harada and Mori filter paper cultures (27) of stools from Langemar and Taraka samples were set up in the laboratory if the sample was adequate, and samples from Hoganeiwa (Aseki) were set up in the field on receipt of the specimens. This enabled identification of hookworm to species

Figure 4. Lae and surrounds, showing the location of the urban study areas – Buimo Road Settlement and Taraka.

by identification of infective larvae (27) and the detection of *Strongyloides* spp infection by the morphology of the infective larvae. Direct smears of all Buimo Road samples and 39 Wasu samples were also examined. Identification of *Strongyloides* spp to species was done according to the morphology of the free-living females (28). Although this identification method is based on the morphology of *S. f. fuelleborni*, the free-living females of *S. f. kellyi* are indistinguishable from *S. f. fuelleborni* (29) and we relied on the geographical distribution to conclude that they were *S. f. kellyi* (29). Where there were no free-living females, identification of *S. f. kellyi* depended on observation of eggs in Macmaster counting chambers or direct smears, and *S. stercoralis* was identified by observation of larvae in direct smears (28).

Statistics

The results were categorized by age groups as follows: 0 years = less than 12 months, 1 year = 12 to 23 months, 2 years = 24 to 35 months, 3 years = 36 to 47 months, 4 years = 48 to 59 months, etc. Differences in prevalences were tested by chi-squared or Fisher's exact test. The significance of double infections was tested by chi-squared. Geometric means were calculated using ln-transformed values and the differences were tested by Student's t test. A result was considered to be significant if p was <0.05.

Results

Necator americanus, *Ascaris lumbricoides*, *Trichuris trichiura* and *Strongyloides fuelleborni* *kellyi* were the major species detected, and the prevalences (% infected) at most survey locations were very high. *Ancylostoma duodenale*, *Strongyloides stercoralis*, *Enterobius vermicularis*, *Rodentolepis* (*Hymenolepis*) *nana* and an unidentified cestode were also detected. *E. vermicularis* is an incidental finding, as the methods used do not usually detect this species.

Results from the Harada and Mori cultures indicated that *N. americanus* was the predominant hookworm species. It was the only hookworm species in cultures from Aseki 1 and Aseki 2 (Langemar), but in 12% of the Taraka cultures yielding hookworm larvae the species was *A. duodenale.* Only Taraka cultures yielded free-living adult *Strongyloides* females: in 70% the species was *S. f. kellyi* and in 30% *S. stercoralis.*

Tables 1 to 5 compare the prevalences (% infected), geometric means (eggs per gram [EPG] faeces) and ln-transformed standard deviations (SDs), for each age group (for children with known ages) for each parasite species (detected by Macmaster technique or weighed direct smear) at each survey location, and Figure 5 shows the four major helminth species detected, comparing the prevalence in each age group at the different survey locations. *N. americanus, A. lumbricoides* and *T. trichiura* were found at all locations. *S. f. kellyi* was detected at Aseki 1, Aseki 2 and Taraka. In general, prevalences of *N. americanus, A. lumbricoides and T. trichiura* increased with age, but in *S. f. kellyi* the mean egg counts and/or prevalence were higher in children under 1 year. Although the figures for mean egg counts in the Tables show an increase with age for *N. americanus* and a decrease with age for *S. f. kellyi,* no significant differences between any geometric mean egg counts in any species could be established

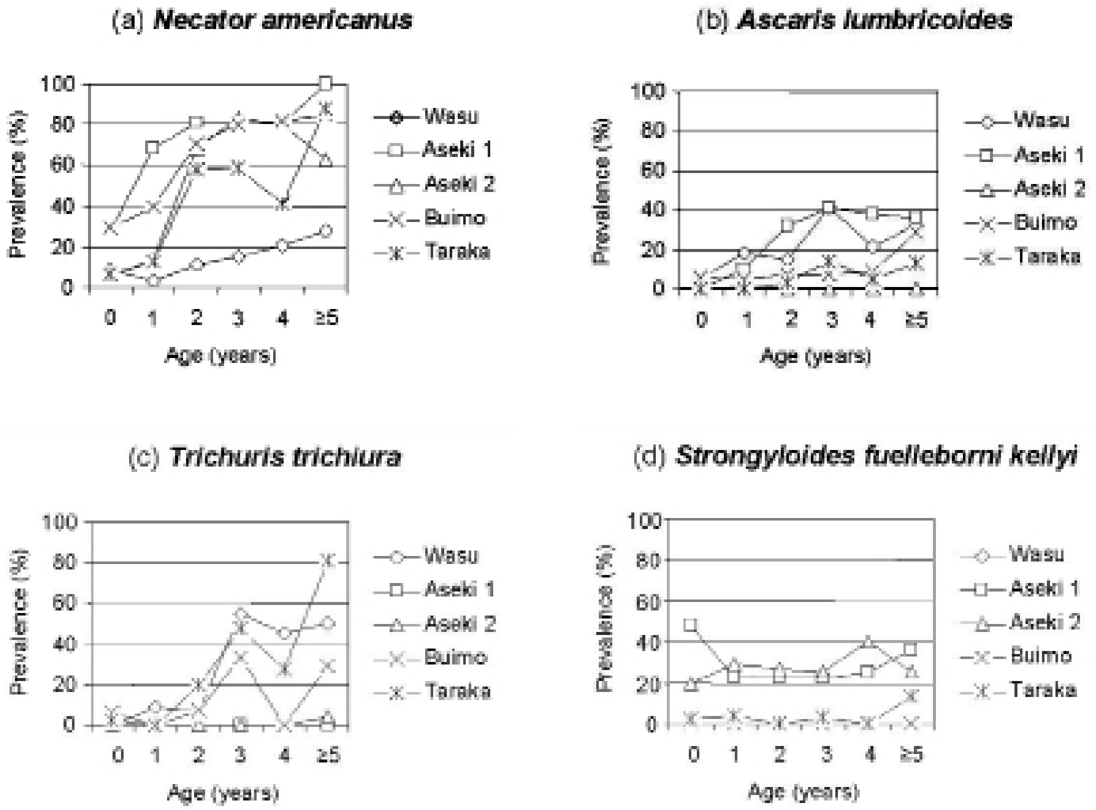

Figure 5. A comparison of the prevalence at each study location for each age group for – (a) *Necator americanus*; (b) *Ascaris lumbricoides*; (c) *Trichuris trichiura*; and (d) *Strongyloides fuelleborni kellyi*.

by the t test. This may be due to the small numbers in each group and the large SDs in the data.

Wasu (rural coastal) (Table 1, Figure 5)

N. americanus, *A. lumbricoides* and *T. trichiura* were detected in children at Wasu, and 14% of children <1 year old were already infected with one or more of these. Hookworm prevalences and mean egg counts were considerably lower than at all the other places surveyed. *A. lumbricoides* prevalence was 41% in 3 year old children. *T. trichiura* prevalence was 55% in 3 year old children, but the mean egg counts were not high. Wasu had the lowest rate of infection by any helminth species for 5-7 year olds of 65%. However, the 21 children aged from 0 to 7 years from the two inland villages (the ages of 9 were not known accurately and therefore not included in the Table) had a higher overall prevalence: 76% for hookworm, 29% for *A. lumbricoides* and 57% for *T. trichiura*. There were no *Strongyloides* eggs or larvae present in any of the 39 direct smears examined.

Aseki 1 (rural uplands) (Table 2, Figure 5)

At Aseki 1, the main helminth species were *N. americanus, A. lumbricoides* and *S.f. kellyi*. 61% of children <1 year old were infected with one or more species. *N. americanus* prevalence in 5-8 year olds was 100%. *A. lumbricoides* prevalence was 41% in the 3 year old age group. Prevalence of *S. f. kellyi* was 48% in children <1 year, significantly higher than in the age groups from 1 to 5 years. The mean egg count was high in the <1 year age group, decreasing with increased age, except that it was very high in the 4 year age group. *E. vermicularis* and *T. trichiura* were present in a few stools, the latter in subjects whose ages were not documented. Direct smears of 133 stools of children of all ages revealed that *A. lumbricoides* eggs were present in 48, compared with 37 identified by the Macmaster egg counting chamber. Thus use of the Macmaster method alone underestimated *A. lumbricoides* prevalence by at least 8%. Of 55 stools cultured, 38 yielded infective hookworm larvae; 37 contained larvae of *N. americanus* only, and in the remaining one the larvae had died and could not be positively identified. 31 cultures (56%) yielded infective *Strongyloide*s larvae, compared with 13 (24%) of the same specimens in which eggs were seen in Macmaster counting chambers. Since all the direct smears which contained *Strongyloides* larvae also contained *Strongyloides* eggs it is concluded that these were larvae of *S. f. kellyi*, though it is possible that some were *S. stercoralis*. The results from the cultures imply that the true prevalence of *S. f. kellyi* is more than double the figures given in Table 2.

Aseki 2 (Langemar) (rural uplands) (Table 3, Figure 5)

The major species present at Langemar were *N. americanus* and *S. f. kellyi.* 20% of children in the <1 year age group were infected with one or more species. *N. americanus* prevalence was 83% in the 3 year age group and 86% in the 6-8 year age group. The prevalence of *S. f. kellyi* at Langemar has already been briefly reported (30). It was between 20% and 40%, similar in most age groups, but the mean egg count was highest in the <1 year age group and declined with age. These results were similar to Aseki 1, except that, at Aseki 1, the prevalence in the <1 year age group was significantly higher than in the other age groups. *Enterobius vermicularis*, *A. lumbricoides* and *T. trichiura* were detected in a few stools. Of the 96 cultures, 11 yielded hookworm larvae, of which 8 had infective *N. americanus* larvae only, and 3 contained first and second stage larvae only, and these cannot be identified to species. 24 cultures out of 96 yielded infective *Strongyloides* larvae. Since the same number of stools had *S. f. kellyi* eggs in the Macmaster egg counting chamber, it is concluded that these larvae were *S. f. kellyi* although the possibility that some were *S. stercoralis* remains.

Buimo Road Settlement (urban) (Table 4, Figure 5)

N. americanus, *A. lumbricoides* and *T. trichiura* were the major species at Buimo Road, though *S. stercoralis* was also present. 41% of children in the <1 year age group were infected with one or more species. *N. americanus* was the most frequent helminth present, increasing in prevalence from 29% at <1 year to 80% at 3 years and 85% at 5 to 7 years. *A. lumbricoides* and *T. trichiura* prevalences were low except in the 3 and 5-7 year age groups. Examination of 91 direct smears revealed that larvae of *Strongyloide*s were present in 4 stools, indicating *S. stercoralis*, and that eggs of *A. lumbricoides* were present in 5 additional stools. Eggs of *S. f. kellyi* were not seen in any specimens from

TABLE 1

Wasu, Morobe North Coast (rural coastal): prevalence (% infected), geometric mean egg count (eggs per gram faeces [EPG])# and ln-transformed standard deviation (SD) of intestinal helminths in children 7 years and under, N = 178

Age (years)	No tested	*Necator americanus**			*Ascaris lumbricoides*			*Trichuris trichiura*			All
	N	Prevalence %	Mean EPG	SD	Prevalence %	Mean EPG	SD	Prevalence %	Mean EPG	SD	Infected %
0	22	9	212	0.49	5	150	-	0	-	-	14
1	34	3	1500	-	18	1230	1.63	9	343	0.73	26
2	27	11	545	1.13	15	1037	1.07	7	260	0.78	22
3	22	15	479	1.70	41**	5853	1.49	55**	587	1.16	68
4	33	21	536	1.16	21	12352	1.22	45	468	1.21	61
5 to 7	40	28	403	1.20	33	4886	1.24	50	329	0.85	65

#by Macmaster method

*presumed *N. americanus*: no testing to determine whether *Ancylostoma duodenale* was present

** *A. lumbricoides* and *T. trichiura:* significant increase in prevalence from 2 year old to 3 year old children, $p<0.05$

TABLE 2

ASEKI 1 (RURAL UPLANDS): PREVALENCE (% INFECTED), GEOMETRIC MEAN EGG COUNT (EGGS PER GRAM FAECES [EPG])# AND LN-TRANSFORMED STANDARD DEVIATION (SD) OF INTESTINAL HELMINTHS IN CHILDREN 8 YEARS AND UNDER, N = 155

Age (years)	No tested	*Necator americanus*†			*Ascaris lumbricoides*			*Strongyloides fuelleborni kellyi*			Other	All
	N	Prevalence %	Mean EPG	SD	Prevalence %	Mean EPG	SD	Prevalence %	Mean EPG	SD	Infected %	Infected %
0	33	27	1195	1.35	0	0	-	48	2461	1.96	0	61
1	31	68*	515	1.24	10	1432	2.23	23***	1101	1.47	3[a]	71
2	37	81	702	1.08	32**	2623	1.51	22	1070	0.99	5[a,b]	89
3	27	81	906	1.20	41	427	1.76	22	492	1.40	4[c]	85
4	16	81	1252	1.24	38	6361	1.07	25	6229	1.02	13[b]	88
5 to 8	11	100	1028	1.27	36	1886	1.30	36	511	1.80	0	100

#by Macmaster method except two stools by weighed direct smear
†confirmed by Harada and Mori cultures
**N. americanus:* significant increase in prevalence from 0 year old to 1 year old children, $p < 0.05$
***A. lumbricoides:* significant increase in prevalence from 1 year old to 2 year old children, $p < 0.05$
****Strongyloides f. kellyi:* significant **decrease** in prevalence from 0 year old to 1 year old children, $p < 0.05$
[a]*R. nana*
[b]*E. vermicularis*
[c]unidentified cestode

TABLE 3

Aseki 2 (Langemar) (rural uplands): prevalence (% infected), geometric mean egg count (eggs per gram faeces [EPG])# and ln-transformed standard deviation (SD) of intestinal helminths in children 8 years and under, N = 140

Age (years)	No tested	*Necator americanus*†			*Strongyloides fuelleborni kellyi*			Other	All
	N	Prevalence %	Mean EPG	SD	Prevalence %	Mean EPG	SD	Infected %	Infected %
0	20	5	1350	-	20	3340	2.19	0	20
1	21	14	300	0.69	29	1780	2.46	10[a,b]	43
2	22	68*	529	1.04	27	841	1.62	0	73
3	12	83	872	0.81	25	833	1.07	33[b]	92
4	20	80	611	1.17	40	510	1.50	20[b]	90
5	24	63	1216	1.07	25	319	1.53	4[b]	79
6 to 8	21	86	1101	1.07	24	215	0.51	24[a,b,c]	90

by Macmaster method

†confirmed by Harada and Mori cultures

**N. americanus:* significant increase in prevalence from 1 year old to 2 year old children, $p<0.05$

[a] *A. lumbricoides*

[b] *E. vermicularis*

[c] *T. trichiura*

TABLE 4

BUIMO ROAD SETTLEMENT, LAE (URBAN): PREVALENCE (% INFECTED), GEOMETRIC MEAN EGG COUNT (EGGS PER GRAM FAECES [EPG])# AND LN-TRANSFORMED STANDARD DEVIATION (SD) OF INTESTINAL HELMINTHS IN CHILDREN 7 YEARS AND UNDER, N = 91

Age (years)	No tested	*Necator americanus*†			*Ascaris lumbricoides*			*Trichuris trichiura*			All
	N	Prevalence %	Mean EPG	SD	Prevalence %	Mean EPG	SD	Prevalence %	Mean EPG	SD	Infected %
0	17	29	492	1.34	6	600	-	6	2100	-	41
1	20	40	2878	1.26	5	1000	-	0	-	-	40
2	14	71*	1966	1.60	7	150	-	7	300	-	71
3	15	80	1724	1.45	7	600	-	33	369	0.86	93
4	11	82	2446	1.66	9	5700	-	0	-	-	82
5 to 7	14	85	2080	1.98	29	1110	1.51	29	770	0.39	93

#by Macmaster method
†presumed *N. americanus*: no testing to determine whether *Ancylostoma duodenale* was present
**N. americanus:* significant increase in prevalence from 1 year old to 2 year old children, $p < 0.05$

Buimo Road. As no cultures were prepared from Buimo Road, it was not known whether *A. duodenale* was present.

Taraka (urban) (Table 5, Figure 5)

The major species at Taraka were *N. americanus, A. lumbricoides*, *T. trichiura* and *S. f. kellyi*. *Ancylostoma duodenale* and *S. stercoralis* were also present. 8% of children in the <1 year age group were infected with one or more species, considerably lower than at Buimo Road. Hookworm prevalence at Taraka increased from 6% in the <1 year age group to 59% in 3 year old children and 88% in 5 year olds. *A. lumbricoides* prevalence was low, but some children had extremely high egg counts. *T. trichiura* prevalence varied between 20% and 81% in the age groups ≥2 years. *S. f. kellyi* was present in most age groups at a low prevalence. Of the 41 cultures that yielded infective hookworm larvae, 36 contained larvae of *N. americanus* only, and 5 contained larvae of *Ancylostoma duodenale*. Of 24 cultures that yielded infective *Strongyloides* larvae (which cannot be identified to species), 8 contained *S. f. kellyi* free-living adults and 3 contained S. *stercoralis* free-living adults.

Comparison of prevalences for each species (Figure 5)

N. americanus (Figure 5a): at all survey locations the prevalence increased with age, and at all except Wasu (predominantly coastal residents) the prevalences were very high by age 5 years. At Buimo Road and Aseki 1, the prevalence was >20% even in children less than 1 year old. The prevalence in 2 year olds was high except at Wasu.

A. lumbricoides (Figure 5b): the prevalence of *A. lumbricoides* at Wasu and Aseki 1 where it was present in appreciable numbers, increased with age. At these locations and at Buimo Road, the prevalence was similar in the ≥5 year age group.

T. trichiura (Figure 5c): the prevalence of *T. trichiura* was very low at the two upland localities. At the coastal and urban localities, the prevalence increased with age and in ≥5 year olds varied from 29% to 81%.

S. f. kellyi (Figure 5d): the prevalence was 48% at Aseki 1 in the <1 year age group, then similar in the other age groups. At Aseki 2 (Langemar), the prevalence was similar in all age groups, and similar to that at Aseki 1 in the age groups ≥1 year. At Taraka it was low in all age groups except the ≥5 year age group, where it was 13%.

S. stercoralis: the prevalence of *S. stercoralis* was low at Buimo Road and Taraka and not detected at Wasu, Aseki 1 or Aseki 2 (Langemar).

Infections with two or more species in children ≥2 years old (Table 6)

The prevalence of double infections was compared with single infections using chi-squared contingency tables in the four surveys where there was an appreciable prevalence of both species, or Fisher's exact test where the numbers were too small for chi-squared. *A. lumbricoides* infection was significantly associated with *T. trichiura* infection at all three locations where there was an appreciable *T. trichiura* prevalence. There was no significant association of hookworm infection with *A. lumbricoides* infection or with *S. f. kellyi* infection. Hookworm infection was associated significantly with *T. trichiura* infection at Taraka, but not at Buimo Road or Wasu. *A. lumbricoides* was significantly associated with *S. f. kellyi* at Aseki 1.

Discussion

The results of this study are in accordance with the earlier high infection rate with intestinal helminths throughout Papua New Guinea (1,2). A hookworm prevalence rate of 90% by the Macmaster method probably indicates universal infection in the community, and at 4 of the 5 localities surveyed the prevalence approached 90% at 5 years of age.

These results also confirm the finding that hookworm is the most common form of intestinal helminth infection, except at coastal localities (1,2), and support the view that most hookworm infections in Papua New Guinea are due to *Necator americanus* (1). Infection with *A. duodenale* is associated with a greater burden of iron deficiency anaemia than *N. americanus* (31). The prevalence of hookworm in <2 year olds in this study (apart from the coastal locality) is similar to earlier surveys in Morobe Province, where 20% of children aged under 2 years and about 80% of those between 2 and 6 years had hookworm (32). Ewers and Jeffrey (1) concluded that

TABLE 5

Taraka (urban): prevalence (% infected), geometric mean egg count (eggs per gram faeces [EPG])# and ln-transformed standard deviation (SD) of intestinal helminths in children 10 years and under, N = 203

Age (years)	No tested	*Necator americanus*†			*Ascaris lumbricoides*			*Trichuris trichiura*			*Strongyloides fuelleborni kellyi*			All
	N	Prevalence %	Mean EPG	SD	Prevalence %	Mean EPG	SD	Prevalence %	Mean EPG	SD	Prevalence %	Mean EPG	SD	Infected %
0	49	6	455	1.37	0	-	-	2	150	-	2	1650	-	8
1	23	13	407	0.87	0	-	-	0	-	-	4	150	-	14
2	40	58	893	1.29	3	79400	-	20	985	1.50	0	0	-	57
3	29	59	1388	1.53	14	35217	1.61	48	636	1.45	3	2400	-	73
4	22	41	2914	1.12	5	300	-	28	370	0.80	0	0	-	68
5	16	88*	2466	1.34	13	2893	1.49	81	838	1.43	13	150	-	94
6 to 10	24	83	922	1.18	4	111900	-	46	974	0.86	4	140	-	96

#by Macmaster method except five stools by weighed direct smear

†includes *Ancylostoma duodenale*, present in 12% of infections

**N. americanus:* significant increase in prevalence from 4 year old to 5 year old children, $p < 0.05$

TABLE 6

PREVALENCE (%) OF DOUBLE INFECTIONS† IN CHILDREN 2 YEARS OLD AND OLDER

Survey point	Number tested	*N. americanus* and *A. lumbricoides*	*N. americanus* and *T. trichiura*	*N. americanus* and *S. f. kellyi*	*A. lumbricoides* and *T. trichiura*	*A. lumbricoides* and *S. f. kellyi*
Wasu	122	7	11	-	17*	-
Aseki 1	91	30	-	22	-	4*
Aseki 2 (Langemar)	99	-	-	23	-	-
Buimo	54	11	19	-	7*	-
Taraka	131	6	32*	-	5*	-

†ignores additional infection by a species other than the two being considered
*$p < 0.05$ by χ^2 or Fisher's exact test

one-third of children <1 year old in Papua New Guinea were infected with hookworm. In this study, this figure was approached at one upland and one urban locality but at the other localities the prevalence was <10%, similar to children at Tari (Southern Highlands) (33) and Karimui (on the southern fringe of the highlands north of Gulf Province) (34). The difference in hookworm prevalence in the lower age groups between the two urban areas surveyed could have been due to the generally better housing and provision of piped water at Taraka.

In contrast, the prevalence of *A. lumbricoides* and *T. trichiura* varied from place to place, as in earlier studies (1,2), and did not seem to conform to a pattern. However, the prevalence of these species was much lower than that of hookworm. The significant association of *A. lumbricoides* and *T. trichiura* with each other at the three localities where there was an appreciable prevalence of *T. trichiura* probably reflects their common mode of transmission, which is different from that of hookworm. This is consistent with the findings of Booth and Bundy in Malaysia (35) and Brooker et al. in Kenya (36). The generally low mean egg counts of *T. trichiura* encountered in this study agree with the results of earlier studies (1,2).

The two upland localities, where there is a high prevalence of *S. f. kellyi,* are both in the zone described by Ashford, Hall and Babona (37) where *S. f. kellyi* is endemic but swollen belly syndrome has not been reported. The absence of *S. f. kellyi* at Buimo Road Health Centre suggests that this species was not originally endemic at Lae. A previous study indicated that the prevalence of *Strongyloides* spp in the Markham Valley (which includes Lae) is very low (38). People from endemic areas have settled in Lae and brought *S. f. kellyi* with them (38,39). The presence of *S. f. kellyi* at Taraka suggests that it is now being transmitted there.

The finding of relatively high mean egg counts and/or high prevalence of *S. f. kellyi* in the younger age groups at Aseki 1 and Aseki 2 (Langemar) is similar to that at a number of other places in PNG (13,37,40). At Taraka, the prevalence of *S. f. kellyi* was low, but the higher egg counts were in children <4 years of age. A lack of association between *S. f. kellyi* and *N. americanus* infection was also found in a highlands fringe people of all ages (34), but contrasts with the results of a study in a different area of Lae, where hookworm was significantly associated with *Strongyloides* spp and also with *T. trichiura* (39).

Strongyloides stercoralis was detected at both urban areas surveyed, but not at the upland and coastal localities where direct smears were examined. Although the majority of severe complicated strongyloidiasis (due to *S. stercoralis*) occurs in infected people with immunosuppression, in a significant number of cases of the severe disease the person has no evidence of immunosuppression. The latter is more frequently observed in toddlers, and persons living in developing countries (16). In addition, malnutrition is frequently associated with severe strongyloidiasis (16).

It is difficult to assess morbidity and mortality due to helminth infections apart from the presentation of acutely ill patients to health centres and hospitals, such as children presenting with severe anaemia (38) or with *S. f. kellyi* swollen belly syndrome (13). The numbers encountered in this way probably underestimate the degree of morbidity. Cooper et al. (41) calculated from field surveys that the morbidity rate from trichuriasis in St Lucia approached 100 per 1000 infected children, yet the morbidity rate as assessed by self-presentation to medical services was only approximately 10 per 1000.

In this study, the number of infections detected by egg counts would have underestimated the true situation. The Macmaster technique is sensitive for hookworm, but comparison with smears showed that it considerably underestimated the prevalence of *A. lumbricoides* at Aseki 1 and Buimo Road, and comparison with cultures showed that the Macmaster technique detected only approximately half the *S. f. kellyi* infections.

Today, much more sensitive tests are available. Serology using the ELISA test for detecting anti-parasite IgG is considerably more sensitive for detecting *S. stercoralis* infection than stool testing (42).

Recently even more sensitive tests have been developed to detect parasite DNA in faecal specimens by the polymerase chain reaction (PCR). In a survey of 77 samples, conducted by Basuni et al. (43), simultaneous PCR testing for *N. americanus, A. duodenale,* *A. lumbricoides* and *S. stercoralis* detected infections in 68% of samples, whereas microscopic examination in the field detected infections in only 8%. Moreover, the tests were conducted on samples that were not refrigerated until arriving at the laboratory. The addition of PCR tests for *T. trichiura*, *S. f. kellyi* and *R. nana* would enable accurate testing for all the intestinal helminths known to be endemic in Papua New Guinea.

The high intensity of infection with *A. lumbricoides* in children can be partly explained by changes in the immune response to helminths in childhood from a non-protective Th1 response to a protective Th2 response by adulthood. Both *A. lumbricoides* and *T. trichiura* have a bell-shaped curve of prevalence and/or infection intensity with age in all age samples. In a study in Cameroon, the intensity in *T. trichiura* increased to age 7 years, and decreased to age 12, then remained constant in the older age groups (44). Non-protective inflammatory cytokines of the Th1 immune response (including TNF-α and IFN-γ) dominated in the young children. In older children the decrease in infection intensity correlated with an increase in protective non-inflammatory Th2 cytokines (44). There was a similar cytokine picture for *A. lumbricoides*, except that in this species the peak of infection intensity occurred at about age 11 years (45).

A study by Barnish and Ashford (40) of prevalence and infection intensity of *S. f. kellyi* with age, using one-month intervals, showed that infection intensity peaked at 12 months and prevalence peaked at 4 years. Our results are in general agreement with this finding. A change in immune response may also account for these observed changes in prevalence and intensity for *S. f. kellyi*.

Hookworm, however, shows an increase in prevalence with age to about 15 years (34), remaining constant during adulthood. In Barnish and Ashford's study (40), hookworm prevalence plateaued at about 9 years of age and infection intensity rose until about 10 years of age, then remained stable.

Although albendazole is now part of standard treatment for children in PNG, and swollen belly syndrome and hookworm anaemia have largely disappeared, it cannot be assumed that the intestinal parasites have disappeared from the population, with the possible exception of *A. lumbricoides*, which is very susceptible to elimination, not only by albendazole but also by pyrantel and piperazine. Places where there is access to medical services, no overcrowding of accommodation, safe water, effective sanitation, and adequate hygiene and sanitary practices, may also be free of intestinal parasites.

Albendazole treatment is very useful clinically by achieving a high egg reduction rate, but the cure rate for *N. americanus* for adults and all age groups at approximately 78% (46) is less than for *Ancylostoma duodenale* at approximately 90% (46). Moreover, the cure rate for children is less still, for example 48% (47) or 64% (48). Similarly, the measured cure rate for *T. trichiura* in adults or all age groups is not high, with reports varying between 43% (49) and 76% (50), but in children it varied between 8% (51) and 41% (47). The story for *S. f. kellyi* is probably similar. ELISA serology has revealed that single-dose albendazole is ineffective at eliminating *S. stercoralis* (52). Consequently, there is an appreciable prevalence of these parasites after treatment, and residual parasites are a source of ongoing transmission. In the case of *S. stercoralis*, the residual parasites re-establish the original patent infection by autoinfection (52).

There is evidence that where there is incomplete elimination of intestinal helminths in a community, the parasites re-establish themselves. In a study in Madang Province (53) *N. americanus* prevalence had returned to preinfection levels two years after treatment and worm burden to 58% of the pretreatment value. In Zanzibar, after a decade of control programs, the prevalence and intensity of hookworm (species unspecified) and *A. lumbricoides* was reduced but still appreciable at 20% and 9% respectively, and the prevalence of *T. trichiura* remained high at 63% (54).

The presence of intestinal helminths in the community increases the risk of individuals succumbing to nutritional deficiency diseases, especially in circumstances when parasite load is heavy and nutritional intake marginal. Young children are particularly at risk because marginal food intakes are common in early childhood, and because their immunological response to the parasites is largely non-protective.

As the result of data showing improvements in child health after deworming, the worldwide community is awakening to the importance of intestinal helminths (55) and the need to control them.

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