The neglected cestode infection: Epidemiology of *Hymenolepis nana* infection among children in rural Yemen

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Article info

Summary

Hymenolepis nana is the most common cestode reported in humans worldwide. It is prevalent among children in the tropics and subtropics, particularly in rural poor communities where sanitation is inadequate or lacking. This cross-sectional study aims to determine the prevalence and significant risk factors of *H. nana* infection among children in rural Yemen. Faecal samples were collected from 498 children and screened for intestinal parasites by using wet mount, formalin-ether concentration and Kato–Katz techniques. A pretested questionnaire was used to collect demographic, socioeconomic, housing condition, and personal hygiene information. Overall, 77.5 % (386/498) of the children were found to be infected by at least one intestinal parasite species. The overall prevalence of *H. nana* was 17.5 % (87/498). Multivariate analysis confirmed that an age of < 6 years (adjusted odds ratio [AOR] = 4.28; 95 % (confidence interval [CI] = 2.04, 8.98), presence of other family members infected with *H. nana* (AOR = 2.48; 95 % CI = 1.45, 4.24), living in the highlands (AOR = 2.87; 95 % CI = 1.56, 5.26), living in a house without improved toilet facilities (AOR = 2.19; 95 % CI = 1.23, 3.88), not washing vegetables before consumption (AOR = 2.11; 95 % CI = 1.06, 4.19), and not washing hands after defecation (AOR = 1.88; 95 % CI = 1.08, 3.27) were the key factors significantly associated with *H. nana* infection among the studied children. In conclusion, *H. nana* is prevalent among children in rural Yemen, particularly among preschool-aged children. Thus, an integrated and effective programme to control intestinal parasitic infections should include preschool-aged children. Such a programme should focus on providing health education on hygienic practices, providing adequate sanitation and improved sources of drinking water, and screening and treating other infected family members.
Keywords: *Hymenolepis nana*; infectious diseases; neglected tropical diseases; epidemiology; children; Yemen

Introduction

The cestode *Hymenolepis nana*, commonly known as the dwarf tapeworm, is the most prevalent cestode in humans, infecting over 75 million people worldwide (King, 2010). Infections occurs most commonly among children in the tropics and subtropics, particu-larly in underprivileged rural communities lacking sanitation and safe drinking water, with a prevalence as high as 55 % (Macnish, 2001; Thompson, 2015). *Hymenolepis nana* is known to infect humans through ingestion of eggs in food or water contaminated with faeces from infected humans or rodents. It can also be acquired by accidental ingestion of arthropods (usually flour beetles and

fleas that serve as intermediate hosts) containing the cysticercoid stages, which then develop into adult worms in the gastrointestinal tract (Galan-Puchades, 2015). Moreover, *H. nana* is the only cestode that can be transmitted directly from person to person as well as autoinfection (endogenous autoinfection) commonly occurs, a feature that may have implications in the prognosis of infection among immunocompromised patients (Lucas *et al.,* 1979; Olson *et al.,* 2003).

Infection with *H. nana*, called hymenolepiasis, is most often asymptomatic, but heavy infections may cause abdominal pain, diarrhoea, nausea, vomiting, loss of appetite, anal itching, and weakness (Mirdha and Samantray, 2002; Cabada *et al.,* 2016). Moreover, headache, dizziness, sleep, and behaviour disturbances are frequently reported (O'Dempsey, 2011). Furthermore, *H. nana* infection may cause serious disseminated disease and death, particularly among immunocompromised individuals, such as AIDS patients and malnourished children (Lucas *et al.,* 1979; Olson *et al.,* 2003; Muehlenbachs *et al.,* 2015; Amer *et al.,* 2018). Nevertheless, despite several reports on *H. nana* infections among children in different countries, data on clinical relevance and morbidity caused by *H. nana* are not convincing. Currently the drug of choice for *H. nana* infection is praziquantel, administered as a single dose (Schenone, 1980; O'Dempsey, 2011).

In Yemen, a Middle Eastern country, approximately 19 million people (70 % of the population) live below the poverty line and are food insecure (UNOCHA, 2019). Moreover, there is a severe lack of sanitation and less than 25 % of the population have access to clean drinking water (Oxfam, 2015). Due to the current widespread civil war, over 55 % of the country's health facilities are totally destroyed, underground water in all Yemeni cities is contaminated with sewage, and the substandard sewage treatment plants are not functioning, putting the entire population at great risk of many infectious diseases (Gavlak, 2015; Al-Mekhlafi, 2018). For instance, since 2015, there have been deadly outbreaks of cholera, dengue, leishmaniasis, and diphtheria (Al-Mekhlafi, 2018; El Bcheraoui *et al.,* 2018; Alghazali *et al.,* 2019).

With regards to intestinal parasites, many studies have reported on the prevalence of different intestinal parasitic infections in Yemen, including soil-transmitted helminth (STH), *Giardia, Entamoeba,* and *Cryptosporidium* infections (Azazy *et al.,* 2002; Alyousefi *et al.,* 2011; Al-Mekhlafi *et al.,* 2016; Alsubaie *et al.,* 2016; Al-Areqi *et al.,* 2017; Al-Mekhlafi, 2017). A few of those studies have included the occurrence of *H. nana* infection in the parasitological assessment, and have reported a prevalence rate ranging between 5 % and 13 %. However, the data on the distribution of *H. nana* infection in Yemen is limited. Moreover, data on the associated risk factors and potential impact of infection on the health and nutritional status of infected individuals is not available. Therefore, the current study was carried out among rural communities in Yemen to determine the prevalence and distribution as well as the associated risk factors of *H. nana* infection.

Materials and Methods

Study design
A community-based cross-sectional study was conducted between February and August 2016 among residents of rural communities in two governorates in Yemen. The study involved the administration of a questionnaire survey, the collection of stool and finger-prick blood samples, and a physical examination. The number of persons per household was recorded and all of the household members were invited to take part in the study. Those who agreed to participate were given unique reference codes that could be used to identify the governorates, villages, households, and individual study participants.

Study area
This study was conducted in two governorates in Yemen, namely, Taiz and Almahweet. Taiz governorate is located in the southwestern part of Yemen, 268 km from the capital Sana'a, at an altitude of 1,400 m above sea level, and has a total population of 2.9 million (NIC, 2019). The climate is hot, with relative humidity varying between 70 % and 90 %, and a mean annual rainfall of approximately 200 mm. There are some streams which are considered, together with many traditional dug wells, the main source of water for both drinking and domestic purposes.

Almahweet governorate, located 110 km northwest Sana'a at an altitude of > 2,000 m above sea level is categorised as a highland area, and has a total population of 0.6 million (NIC, 2019). The climate is moderate in summer and cold in winter, with relative humidity varying between 20 % and 50 %, and a mean annual rainfall of approximately 400 mm. There are some springs and streams in this governorate which are used to provide a supply of water for agricultural and household uses. In addition, numerous traditional small and medium-sized uncovered troughs for drinking and domestic water are located throughout the governorate. Agriculture is the main occupation of the studied population in both governorates. Cereals, vegetables, fruits and khat are the main cultivated plants in Taiz while coffee and khat are the main types of crop grown in Almahweet.

Overall, six districts (three from each governorate) were selected randomly from an official list of districts provided by the respective health office of each governorate. The selected districts were Alwaziyah, Maqbanah, and Mawaiah, in Taiz, and Alrujum, Altawilah, and Shibam-Kawkaban in Almahweet (Figure 1). Twenty-five households, the unit of sampling, were selected from each district by using a systematic random sampling technique.

Sample size and study population
After obtaining consent from the parents, all children at households were invited to participate in the study. A total of 672 children (369 boys and 303 girls) aged between 2 and 17 years were involved in the study and were given containers for stool samples. However, only 550 (81.8 %) children delivered the containers for examination
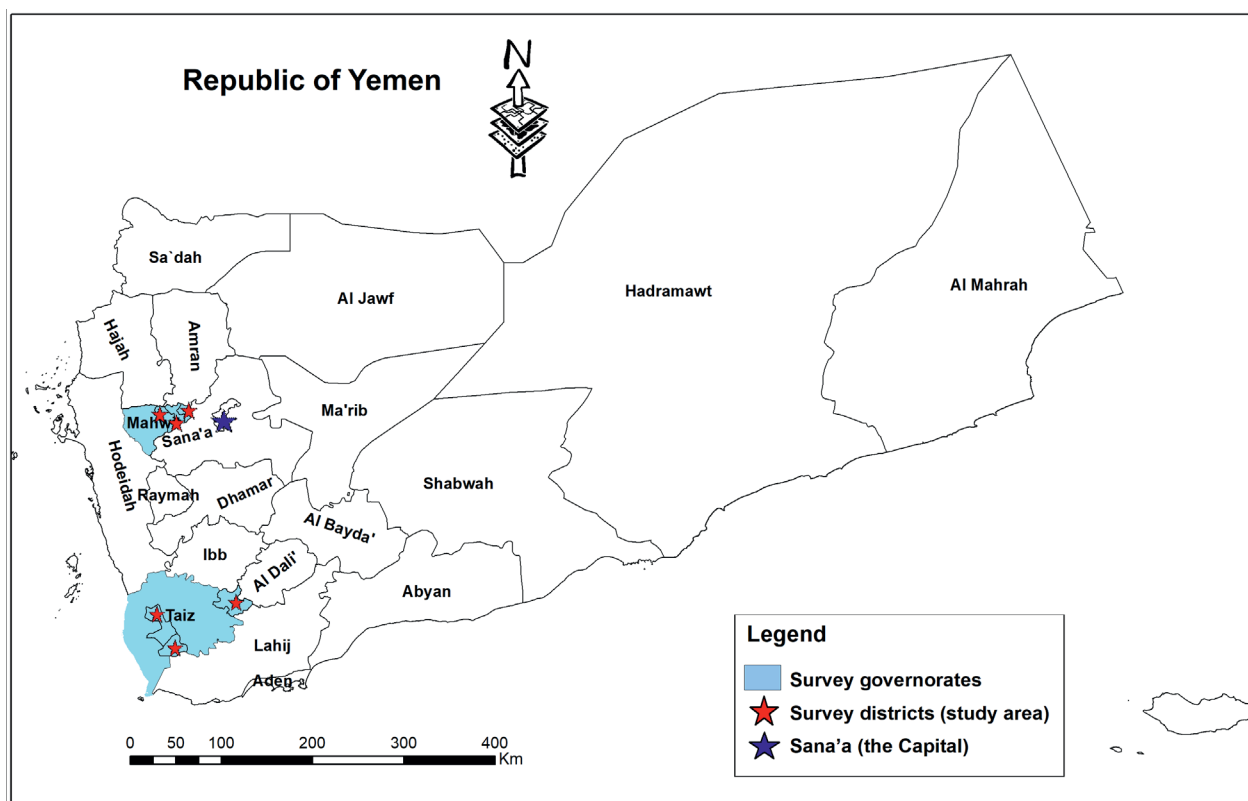
Fig. 1. A geographic map showing the districts and governorates involved in the study (6 districts within two governorates).
The map was created using a licensed Esri ArcGIS 10.7 software.

while 122 (18.2 %) failed to provide samples. A further 52 (7.7 %) children were excluded due to empty containers. Hence, a total of 498 children who had provided their faecal samples for examination and whose parents had provided complete questionnaire information were considered in the data analysis. Of these 498 participants, 256 children (169 boys and 87 girls) were from Taiz governorate and 242 children (151 boys and 91 girls) were from Almahweet governorate. This final number of participants met the estimated minimum sample size required for this study, which was calculated according to the WHO practical manual for sample size calculation (Lwanga and Lemeshow, 1991). Based on a 5 % level of significance, a 95 % confidence level, and design effect of 2, the minimum sample size was 392, assuming that the prevalence of *H. nana* infection in Yemen was as high as 13 % as reported in a previous study (Raja'a *et al.,* 2000).

Questionnaire survey
The children and their parents were interviewed, in their home settings, to fill out a structured pre-tested questionnaire for their family background and socioeconomic information. The questionnaire was designed in three parts. The first part centred around demographic data of the participant including age, sex, address and number of household members. The second part involved questions concerning the socioeconomic status (e.g. parents'

occupational and educational status and family monthly income) and housing conditions (e.g. availability of improved toilets in the household, types of drinking water supply, and presence of domestic animals at household). The third part involved questions concerning personal hygiene (e.g. washing hands before eating, after defecation and after playing with soil, boiling drinking water before consumption, washing vegetables and fruits before consumption, indiscriminate defecation and cutting nails periodically) and clinical signs and symptoms related to intestinal parasitic infections (e.g. abdominal pain, diarrhoea, nausea and vomiting as well as a history of receiving anthelmintics treatment). The interviews were conducted by two research assistants who had received training on questionnaire administration and the purpose of the study.
Moreover, housing conditions were observed and recorded by the survey team. For instance, the toilet and water supply facilities in the households were observed and classified into two types, namely, unimproved and improved, according to the WHO and UNICEF criteria (WHO/UNICEF, 2015). Accordingly, a pour flush toilet was classified as an improved toilet while a pit latrine without a slab was classified as an unimproved toilet. Similarly, piped water supplies were classified as improved water sources while other domestic water sources such as rain, wells, uncovered cistern/troughs, and streams were classified as unimproved sources.

Stool examination

Each child was given a 100-mL clean container with wide mouth and screw cap. Subjects were requested to provide an adequate fresh stool sample and instructed on how to avoid possible contamination in the process of collection at home. The collected containers were properly labelled, placed into proper plastic bags, kept in a cool ice box (4 – 6°C), and transported for examination to the nearest health centre laboratory equipped with standard facilities within 5 hours of collection.

The stool samples were examined for the presence of *H. nana* and other intestinal parasites by using wet mount and formalin-ether sedimentation methods according to Cheesbrough (2005). In addition, the samples were screened by the Kato–Katz technique and egg counting was performed (WHO, 2006). The intensity of infection was recorded as number of eggs per gram (epg) of stool and classified as follows: 1 – 1,999: light, 2,000 – 9,999: moderate, and ≥ 10,000 heavy (Chero *et al.,* 2007; Matthys *et al.,* 2011). A sample was considered positive if *H. nana* ova were detected by using any one of the three methods. For quality control, 10 % of the stool samples were selected randomly and examined by another research assistant using the formalin-ether sedimentation technique.

Statistical analysis

Data was entered into a Windows 10 Excel spreadsheet, checked for accuracy, and then entered into the Statistical Package for the Social Sciences (SPSS) version 18 (Chicago, USA: IBM Inc.) for analysis. The dependent (*H. nana* infection) and independent variables (demographic, socioeconomic, housing conditions, and personal hygiene) were considered as categorical variables and presented as frequencies and percentages. The associations between variables were assessed by using Pearson's chi-square test. Odd ratios (ORs) and 95 % confidence intervals (CIs) were also computed. In addition, a multiple logistic regression analysis was used to identify the significant risk factors of *H. nana* infection. In order to retain all possible risk factors, variables that showed an association with a *P* level ≤ 0.25 in the univariate analysis were considered in the multiple logistic regression models (Bendel and Afifi, 1977). Adjusted ORs and their corresponding 95 % CIs were calculated based on the final model. The level of statistical significance was set as *P* < 0.05 for all analyses.

Ethical Approval and/or Informed Consent

All procedures performed in studies involving human participants were in accordance with ethical standards of the institutional ethical committee and with the 1964 Helsinki declaration and its later amendments.

The study protocol was approved by the Medical Ethics Committee of the University of Malaya Medical Centre (Ref. No. 201411-805). Moreover, permission to commence sampling and data collection was also obtained from the respective health office of each governorate. A written and signed or thumb-printed informed consent was obtained from the parents for their participation as well as on behalf of their children.

Results

General characteristics of the participants

Four hundred and ninety-eight children aged between 2 and 17 years, with a mean age of 9.4 ± 4.3 years participated voluntarily in the study. Of them, 320 (64.3 %) were boys and 178 (35.7 %) were girls. Overall, approximately two-thirds (62.9 %) of the participants lived in households that had a low monthly income (< USD 80), and 43.6 % of households contained an educated father (i.e., had completed at least 6 years of formal education). Poverty prevails in the study areas as evidenced by poor housing and living conditions, especially in Taiz governorate. In Taiz, most of the houses are made of stones and mud while comparatively few houses are made of bricks and concrete, whereas in Almahweet most of the houses are made of fired bricks or concrete. About a quarter (27.7 %) of the subjects lived in houses that had an improved water supply while 37.8 % lived in houses with an improved toilet. The general characteristics of the participants are shown in Table 1.

Prevalence and distribution of H. nana infection

The data on the prevalence and distribution of *H. nana* infection according to age, gender, and location is presented in Figure 2. The overall prevalence of *H. nana* infection was 17.5 % (87/498). An age-dependency distribution was found, where the prevalence rate of infection decreased with age (χ^2 = 18.839; df = 2; *P* < 0.001). The highest rate of infection was observed among pre-school-aged children (< 6 years) (29.3 %; 39/133) while the lowest prevalence (10.5 %; 15/143) was seen among those aged over 12 years. With regards to gender, there was a higher prevalence of infection among boys compared to girls (19.1 % vs 14.6 %). However, this difference was not statistically significant (χ^2 = 1.575; df = 1, *P* = 0.209). It was also found that the majority (81.6 %; 71/87) of the *H. nana* infections were of light intensity while only 15.0 % (13/87) and 3.4 % (3/87) were of moderate and heavy intensity, respectively.

With regards to the clinical presentation (Table 2), the proportion of gastrointestinal symptoms (i.e. abdominal pain, diarrhoea, vomiting, nausea, constipation, and loss of appetite) was higher among *H. nana*-infected children compared to non-infected children (74.7 % vs 68.4 %). However, this difference was not statistically significant (x^2 = 1.362; *P* = 0.243). Nonetheless, the proportion of abdominal pain (39.1 % vs 27.7 %; *P* = 0.035) was significantly higher among *H. nana*-infected children than among their non-infected peers. Moreover, there was a significantly higher proportion of dizziness among *H. nana*-infected children than among non-infected children (20.7 vs 11.4 %; *P* = 0.020). Likewise, a significant association was reported between *H. nana* infection and anal itching (*P* = 0.024).

Table 1. General characteristics of the children participated in the study (n= 498).

Characteristics	n (%)
Age (years)	
< 6 (preschool)	133 (26.7)
6 – 12	222 (44.6)
> 12	143 (28.7)
Gender	
Boys	320 (64.3)
Girls	178 (35.7)
Residence (governorate)	
Almahweet (Highland)	242 (48.6)
Taiz (Coastal/foothill area)	256 (51.4)
Father's occupational status	
Not working	80 (16.1)
Farmers and daily workers	310 (62.2)
Government employees/professionals	108 (21.7)
Father's educational level (at least primary)	217 (43.6)
Low household monthly income (< USD 80)	313 (62.9)
Family size (≤ 7 members)	283 (56.8)
Improved water supply at household	138 (27.7)
Presence of improved toilet in house	310 (62.2)
Presence of domestic animals at household	321 (64.5)

All values are number (%).

The children were also found to be infected with *Trichuris trichiura* (10.8 %), *Ascaris lumbricoides* (13.1 %), hookworm (12.4 %), *Schistosoma mansoni* (10.6 %), *Enterobius vermicularis* (17.9 %), *Giardia duodenalis* (19.1 %) and *Entamoeba histolytica/dispar* (24.7 %). Overall, only 28 % of the *H. nana* infections were single infections while 72 % were coinfections with one or more of the above-mentioned intestinal parasites. Thus, it might not be possible to elucidate the exact associations between the different infections and the gastrointestinal symptoms.

Risk factors of H. nana infection

Potential factors associated with *H. nana* infection were analysed by univariate and multivariate analyses, the results of which are presented in Tables 3 and 4, respectively. The results in Table 3 show that the prevalence of *H. nana* infection was significantly higher among children aged below 6 years when compared with those aged over 12 years ($P < 0.001$) as well as those aged 6 – 12 years ($P = 0.029$). There was also a significantly higher prevalence of *H. nana* among children living in the highlands at altitude of > 2,000 m above sea level (Almahweet governorate) as compared to those living in coastal/foothill areas at altitude of 1,400 m above sea level (Taiz governorate) (21.9 % vs 13.3 %; $P = 0.011$). Moreover, there was a significantly higher prevalence of

H. nana among children whose fathers were aged < 40 years and among children whose fathers were not working as compared to those whose fathers were aged ≥ 40 years (21.4 % vs 13.6 %; $P = 0.028$) and those whose fathers were working as government employees/professionals (25.0 % vs 12.0 %; $P = 0.021$). Furthermore, the prevalence of *H. nana* was significantly higher among children from families with a low household monthly income compared to children from families with a household monthly income of ≥ USD 80 (20.1 % vs 13.0 %; $P = 0.041$). Interestingly, there was a significantly higher prevalence of infection among children who lived with other family members infected with *H. nana* when compared to their peers in non-infected households (29.2 % vs 12.2 %; $P < 0.001$).

There was a significantly higher likelihood of being infected with *H. nana* among children living in a house without a toilet compared to those living in a house with toilet facilities (22.9 % vs 14.2 %; $P = 0.013$). With regards to personal hygiene, there was a significantly higher prevalence of infection among children who did not practise handwashing after defecation (23.6 %) or after playing with soil (22.1 %) and those who did not wash vegetables (24.3 %) or fruits (23.3 %) before consumption than among their counterparts who followed the above-mentioned hygiene practices ($P < 0.05$).
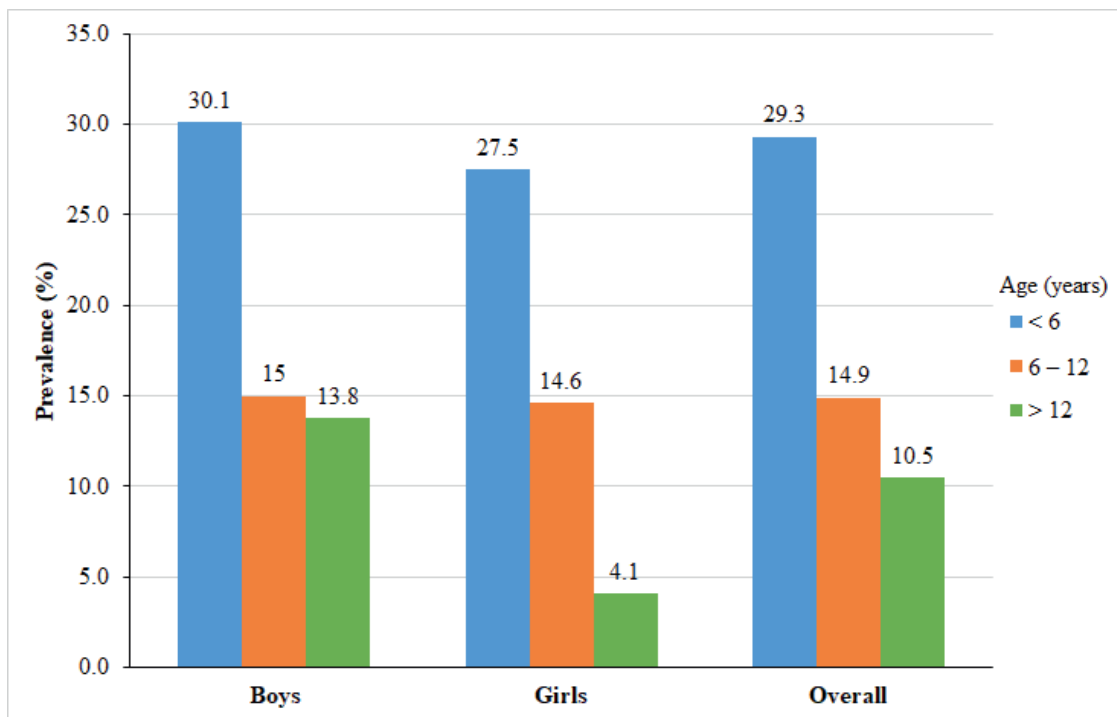
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Fig. 2. Prevalence of *Hymenolepis nana* infection among the participants according to their age and gender (n = 498).

The results of the multiple logistic regression for the significant risk factors (Table 4) showed that children aged below 6 years had 4.28 times higher odds of having a *H. nana* infection when compared with older children. Moreover, children living in the highlands (AOR = 2.87), those living in a house without an improved toilet (AOR = 2.19), and those living with other infected family members (AOR = 2.48) had significantly higher odds of acquiring *H. nana* when compared to their counterparts. Similarly, children who did not wash their hands after defecation and those who did not wash vegetables before consumption had approximately two times the odds of being infected compared to their counterparts.

Discussion

The current study is the first to provide information on the epidemiology of *H. nana* in Yemen. The findings revealed a relatively high prevalence (15.5 %) of *H. nana* infection among rural children in Taiz and Almahweet governorates. Moreover, this is the highest

Table 2. Distribution of clinical signs and symptoms among *Hymenolepis nana*-infected children in rural Yemen (n = 498).

Signs and symptoms	Overall	*Hymenolepis nana* infection		
		Positive (n = 87)	Negative (n = 411)	χ^2 (*P*)
Abdominal pain	148	34 (39.1)	114 (27.7)	4.423 (0.035)*
Diarrhoea	90	19 (21.8)	71 (17.3)	1.010 (0.315)
Constipation	33	5 (5.7)	28 (6.8)	0.132 (0.717)
Nausea	97	16 (18.4)	81 (19.7)	0.079 (0.778)
Vomiting	41	9 (10.3)	32 (7.8)	0.622 (0.430)
Loss of appetite	115	19 (21.8)	96 (23.4)	0.093 (0.760)
Anal itching	145	34 (39.1)	111 (27.0)	5.071 (0.024)*
Dizziness	65	18 (20.7)	47 (11.4)	5.418 (0.020)*
Headache	76	19 (21.8)	57 (13.9)	3.527 (0.060)
Fatigue	61	8 (9.2)	53 (12.9)	0.914 (0.339)

All values are number (%).
χ^2 Chi-square test statistic.
* Significant difference between the groups (*P* < 0.05).

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Table 3. Univariate analysis of factors associated with *Hymenolepis nana* infection among children in rural Yemen (n = 498).

Variables	H. nana infection			
	No. examined	Infected n (%)	OR (95% CI)	P value
Age (years)				
< 6 (preschool)	133	39 (29.3)	3.54 (1.84, 6.80)	< 0.001*
6 – 12	222	33 (14.9)	1.49 (0.78, 2.86)	0.227
> 12	143	15 (10.5)	1	
Gender				
Boys	320	61 (19.1)	1.38 (0.83, 2.27)	0.209
Girls	178	26 (14.6)	1	
Family size				
> 7 members (large)	215	41 (19.1)	1.21 (0.76, 1.93)	0.412
≤ 7 members	283	46 (16.3)	1	
Father's age (years)				
< 40	248	53 (21.4)	1.73 (1.08, 2.77)	0.028*
≥ 40	250	34 (13.6)	1	
Residence				
Almahweet (Highland)	242	53 (21.9)	1.83 (1.14, 2.94)	0.011*
Taiz (Coastal/foothill area)	256	34 (13.3)	1	
Father's educational level				
Non educated (< 6 years)	281	52 (18.5)	1.18 (0.74, 1.89)	0.489
Educated (≥ 6 years)	217	35 (16.1)	1	
Father's occupational status				
Not working	80	20 (25.0)	2.44 (1.13, 5.26)	0.021*
Farmers and daily workers	310	54 (17.4)	1.54 (0.81, 2.95)	0.189
Government employees/professionals	108	13 (12.0)	1	
Household monthly income				
< USD 80 (low)	313	63 (20.1)	1.69 (1.02, 2.82)	0.042*
≥ USD 80	185	24 (13.0)	1	
Presence of improved toilet in house				
No	188	43 (22.9)	1.79 (1.12, 2.86)	0.013*
Yes	310	44 (14.2)	1	
Source of drinking water				
Unimproved (well, streams, rain, dams)	360	70 (19.4)	1.72 (0.97, 3.04)	0.061
Improved (piped water)	138	17 (12.3)	1	
Presence of domestic animals at household				
Yes	321	59 (18.4)	1.20 (0.73, 1.96)	0.471
No	177	28 (15.8)	1	
Presence of other family members infected with *H. nana*				
Yes	154	54 (29.2)	2.97 (1.85, 4.77)	< 0.001*
No	344	42 (12.2)	1	
Washing hands before eating				
No	162	32 (19.8)	1.26 (0.78, 2.04)	0.351

Yes	336	55 (16.4)	1	
Washing hands after defecation				
No	144	34 (23.6)	1.76 (1.08, 2.85)	0.021*
Yes	354	53 (15.0)	1	
Washing hands after playing with soil				
No	199	44 (22.1)	1.69 (1.06, 2.69)	0.026*
Yes	299	43 (14.4)	1	
Indiscriminate defecation				
Yes	325	60 (18.5)	1.22 (0.76, 2.01)	0.424
No	173	27 (15.6)	1	
Cutting nails periodically				
No	278	52 (18.7)	1.22 (0.76, 1.95)	0.414
Yes	220	35 (15.9)	1	
Washing vegetables before eating				
No	152	37 (24.3)	1.91 (1.18, 3.07)	0.008*
Yes	346	50 (14.5)	1	
Washing fruits before eating				
No	133	31 (23.3)	1.68 (1.03, 2.74)	0.038*
Yes	365	56 (15.3)	1	
Boiling water before drinking				
No	454	81 (17.8)	1.38 (0.56, 3.36)	0.483
Yes	44	6 (13.6)	1	

Reference group marked as OR = 1. OR, Odds ratio. CI, Confidence interval
* Significant association (unadjusted $P < 0.05$ using the Bonferroni correction for multiple comparisons)

prevalence reported in Yemen and the Middle East region. Previous studies among primary schoolchildren in different governorates in Yemen reported prevalence rates between 2.3 % and 13 % (Raja'a et al., 2000; Azazy et al., 2002; Raja'a and Mubarak, 2006; Al-Haddad and Baswaid, 2010; Al-Mekhlafi et al., 2016; Alsubaie et al., 2016; Alwabr and Al-Moayed, 2016). The highest prevalence reported before the current study was 13 % among children aged 5 – 18 years in Ibb governorate, which borders Taiz (Raja'a et al., 2000) followed by 12.2 % reported among 320 children aged 6 – 16 years in Hajjah governorate, which borders Almahweet (Alharbi et al., 2019). This variation in the prevalence of H. nana could be attributed to the different areas and populations studied as well as to the methods utilised for stool examination. A much lower prevalence rate (0.9 – 1.4 %) was reported among participants aged 2 – 80 years attending hospitals and clinics in Sana'a City and Taiz governorate (Alyousefi et al., 2011; Al-Harazi, 2016). The higher prevalence reported by the current study may also be explained by the devastating ongoing civil war in Yemen that has led to approximately 55 % of healthcare facilities being totally non-functioning (Gavlak, 2015; UNOCHA, 2019). Moreover, mass drug administration (MDA), the key strategy for controlling schistosomiasis and STH infections in Yemen, has been largely interrupted due to the war (Al-Mekhlafi et al., 2018).

A much lower prevalence of H. nana infection is commonly reported worldwide (Oliveira et al., 2015; Asai et al., 2016; Spinicci et al., 2018; Periago et al., 2018; von Huth et al., 2019). However, a similar prevalence (17.4 %) has been reported among children aged 3 – 16 years in the highlands of Peru (Cabada et al., 2016). In contrast, a higher prevalence rate has been reported in different countries around the world. For instance, 25.8 % in 602 children aged 7 – 11 years in western Tajikistan (Matthys et al., 2011), 27.5 % (195/708) in 708 children aged 8 – 16 years in Nepal (Shrestha et al., 2018), 28.3 % in 405 children aged less than 13 years in Ethiopia (Amare et al., 2013), 33 % among 500 preschool children of displaced communities in Khartoum, Sudan (Abdel Hamid et al., 2015), 50 % in 150 cases of phlyctenular eye disease in Egypt (Hussein and Nasr, 1991) and 55 % among the aboriginal community in northwestern Australia (Reynoldson et al., 1997).

With regards to the risk factors of H. nana infection, the current study identified age below 6 years, presence of other family members infected with H. nana, highlands residency, living in a house without toilet facilities, not washing hands after defecation, and not washing vegetables before consumption as the significant risk factors. Interestingly, the current study revealed a significantly higher

Table 4. Multivariate analysis of factors associated with *H. nana* infection among participants in rural Yemen (n = 498).

Variables	*H. nana* infection		
	Adjusted OR	95% CI	*P*-value
Age (< 6 years)	4.28	2.04, 8.98	< 0.001*
Gender (males)	1.32	0.76, 2.29	0.332
Father's age (< 40 years)	1.63	0.98, 2.55	0.060
Residence (highland)	2.87	1.56, 5.26	0.002*
Father's occupational status (not working)	1.68	0.64, 4.42	0.289
Father's occupational status (farmers and daily workers)	0.94	0.40, 2.23	0.944
Household monthly income (< USD 80)	1.12	0.57, 2.37	0.679
Presence of improved toilet in house (no)	2.19	1.23, 3.88	0.008*
Source of drinking water (unimproved)	1.37	0.73, 2.59	0.325
Presence of other family member infected with *H. nana* (yes)	2.48	1.45, 4.24	0.001*
Washing hands after defecation (no)	1.88	1.08, 3.27	0.025*
Washing hands after playing with soil (no)	1.50	0.86, 2.61	0.149
Washing vegetables before eating (no)	2.11	1.06, 4.19	0.034*
Washing fruits before eating (no)	0.81	0.40, 1.62	0.549

OR, Odds ratio. CI, Confidence interval.
* Significant association (Adjusted *P* < 0.05).

prevalence of *H. nana* infection among preschool-aged children (below 6 years) compared to older children. This is inconsistent with previous studies conducted in Zimbabwe (Mason and Patterson, 1994) and Peru (Cabada *et al.,* 2016).

Currently, studies specifically among preschool children in Yemen are not available. However, a linear association between the prevalence of intestinal parasites and age is well documented. For instance, it is commonly reported that older children aged 10 years and above are more likely to contract infections from the environment (Cabada *et al.,* 2016; Al-Mekhlafi *et al.,* 2019). However, the nature and extent of the association might be different for some parasites, specifically *H. nana* and *E. vermicularis* because these can be transmitted directly from human to human and through auto-reinfection. The acquisition of *H. nana* infection can also be linked to the presence of other family members infected with *H. nana*, which the current study also identified as a risk factor of *H. nana*. This association might be attributed to the horizontal transmission (intrafamily transmission) of intestinal parasitic infections among family members. For instance, in poor communities an infected mother could transmit *H. nana* by preparing food for her family members, and infected children could also transmit the parasite to their siblings. These suppositions are consistent with previous studies on *H. nana* and other intestinal parasites such as *Giardia*, *Entamoeba* and STH in Yemen and elsewhere (Mason and Patterson, 1994; Elyana *et al.,* 2016; Al-Areeqi *et al.,* 2017; Al-Mekhlafi, 2017)

The higher prevalence of *H. nana* among preschool children may have an important implication for the schistosomiasis and STH infections control programmes in Yemen and other countries that are endemic for *Schistosoma* and *H. nana* infections. These programmes cover only schoolchildren, whereas preschool-aged children and non-enrolled school-aged children, particularly girls, are not offered treatment (Oshish *et al.,* 2011; Faust *et al.,* 2020). In such circumstances, preschool children will continue serving as a source of infection within endemic communities, and other age groups will be reinfected within a short period of time. Therefore, it is vital to include preschool-aged children in MDA with praziquantel to improve the control of schistosomiasis and other intestinal parasitic infections (including *H. nana*) (Soares Magalhães *et al.,* 2013; Asai *et al.,* 2016). However, the absence of paediatric formulations of praziquantel hampers the routine treatment of preschool-aged children. Hence, the need for a paediatric formulation of praziquantel is pressing, and efforts are being undertaken to make it available by 2020 (Coulibaly *et al.,* 2017; Fenwick, 2017). Indeed, the Pediatric Praziquantel Consortium, an international partnership, was established in 2012 with the goal of developing a pediatric-friendly praziquantel orally dispersible tablet formulation and obtaining regulatory approval of its use for treating schistosomiasis in children aged from 3 months to 6 years (https://www. pediatricpraziquantelconsortium.org/). Two paediatric clinical trials (Phase I and II) have been conducted in sub-Saharan Africa in the frame of the Consortium's project, and the Phase III trials of safety and efficacy of the developed formulation are ongoing (N'Goran *et al.,* 2019; Faust *et al.,* 2020).

In the current study, *H. nana* infection was found to be significantly higher among children residing in the highlands (Almahweet). These children had three times the odds of acquiring *H. nana* compared to their peers residing in coastal/foothill areas (Taiz).

While the underlying reasons for such association remain unexplained, a similar topographical variation in *H. nana* prevalence has been reported in Peru where prevalence rates of 17.4 % and 7.6 % were found among children in coastal and highlands areas, respectively (Cabada *et al.,* 2016; Vilchez Barreto *et al.,* 2017). This suggests that further studies are needed on the impact of environmental and meteorological factors on the prevalence and distribution of *H. nana*.

It is also well documented that intestinal parasitic infections are particularly common in children living in underprivileged areas where poverty prevails and where sanitation and an improved water supply are lacking (Vaz Nery *et al.,* 2019). In the current study, living in a house without functioning toilet facilities doubled the odds of children acquiring a *H. nana* infection. This is in agreement with previous studies in Mexico (Martinez-Barbabosa *et al.,* 2010) and Peru (Vilchez Barreto *et al.,* 2017). These two studies (Martinez-Barbabosa *et al.,* 2010; Vilchez Barreto *et al.,* 2017), as well as studies conducted in Kyrgyzstan (Steinmann *et al.,* 2010) and Tajikistan (Matthys *et al.,* 2011), have also identified the lack of an improved water supply in the household as a significant risk factor of *H. nana*; an association that was not reported in the current study.

Personal hygiene practices play a crucial role in the transmission of intestinal parasitic infections (Gungoren *et al.,* 2007). The current study found that children who did not wash their hands after defecation and those who did not wash vegetables before consumption were approximately twice as likely to be infected with *H. nana* compared with children who practised good personal hygiene. This is consistent with previous reports on intestinal parasitic infections (Gulliver *et al.,* 2014; Elyana *et al.,* 2016; Al-Areeqi *et al.,* 2017; Al-Mekhlafi, 2017). Thus, the findings of the current clearly speak to the imperative need for improved sanitation, water and hygiene (WASH) facilities in the rural communities of Yemen. *Hymenolepis nana* is the only cestode that does not necessarily require an intermediate host for its transmission from person to person. Infected individuals who do not wash their hands with soap after defecation may transmit infective eggs of *H. nana* to others by a variety of means including shaking hands and processing food. A previous randomised controlled trial showed that frequent handwashing with soap significantly decreased the *H. nana* reinfection rate among schoolchildren (Mahmud *et al.,* 2015). Similarly, a systematic review of studies on the parasitic contamination of fruits and vegetables processed for human consumption showed that *H. nana* was among the most commonly reported parasites (Karshima *et al.,* 2018).

Although *H. nana* infection is usually asymptomatic, it has been associated with gastrointestinal symptoms among children. The current study found a significant association between *H. nana* infection and abdominal pain and anal itching as well as dizziness. Although skin manifestations such as pruritus ani (anal itching) are rare in *H. nana* infection, a significant association between *H. nana* infection and anal itching was reported among the studied children. A previous study in Peru showed that *H. nana* infection is significantly associated with diarrhoea, jaundice, and headache (Cabada *et al.,* 2016). Likewise, *H. nana*-infected Sudanese children have been found to have a nine-fold higher risk of diarrhoea compared with uninfected children (Abdel Hamid *et al.,* 2015). Moreover, *H. nana* infection has been identified as a significant predictor of malnutrition and anaemia (Mohammad and Hegazi, 2007; Oliveira *et al.,* 2015; Spinicci *et al.,* 2018). Thus, further studies are warranted on the burden and clinical profile of *H. nana* infection among children in rural Yemen.

It should be noted that the current study has limitations that should be considered when interpreting the findings. Firstly, a cross-sectional study design was used for this study, which limited the ability to infer causality between *H. nana* infection and explanatory variables. Secondly, a single faecal sample was collected from each child instead of the ideal three consecutive days of sample, which would have enhanced the sensitivity of parasite diagnosis (Hall, 1981). Thus, the prevalence of *H. nana* infection reported in the current study might have been underestimated.

In conclusion, this study revealed a high prevalence of *H. nana* infection among children in rural Yemen, particularly among preschool-aged children. Therefore, preschool-aged children should be included in the national schistosomiasis and STH control programme. In addition to periodic MDA, the control programme should focus on providing health education on hygienic practices, the introduction of adequate WASH facilities and screening and treating other infected family members. These measures are crucial because they will help to significantly reduce the prevalence of *H. nana* and other intestinal parasites among rural communities in Yemen. Also, further investigations are required to evaluate the true public health burden and the clinical profile of *H. nana* infection in these communities in order to guide future control efforts against intestinal parasites.

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Conflict of interest

The author states no conflict of interest.

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