Wealth and Its Associations with Enteric Parasitic Infections in a Low-Income Community in Peru: Use of Principal Component Analysis

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Abstract. The association of wealth and infections with *Giardia*, *Cryptosporidium*, *Cyclospora*, and microsporidia were examined in a longitudinal cohort conducted in Peru from 2001 to 2006. Data from 492 participants were daily clinical manifestations, weekly copro-parasitological diagnosis, and housing characteristics and assets owned (48 variables), and these data were used to construct a global wealth index using principal component analysis. Data were analyzed using continuous and categorical (wealth tertiles) models. Participant's mean age was 3.43 years (range = 0–12 years), with average follow-up of 993 days. Univariate and multivariate analyses identified significant associations between wealth and infections with *Giardia* and microsporidia. Participants with greater wealth indexes were associated with protection against *Giardia* ($P < 0.001$) and persistent *Giardia* infections (> 14 days). For microsporidia, greater wealth was protective ($P = 0.066$ continuous and $P = 0.042$ by tertiles). Contrarily, infections with *Cryptosporidium* and *Cyclospora* were independent of wealth. Thus, subtle differences in wealth may affect the frequency of specific parasitic infections within low-income communities.

INTRODUCTION

Diarrhea is a leading cause of mortality and morbidity among children living in low-income settings.¹ It accounts for one in five deaths in children under 5 years and has been associated with nutritional deficiencies, growth stunting,^{2,3} lost days of education, and lower cognitive ability.⁴

A number of risk factors for diarrhea have been identified including younger age,⁵ lack of access to running water,⁶ lack of proper sanitation, presence of young children in the household, presence of certain animals in the house,⁷ poor hygiene practices, poor nutrition status,⁸ and low parental education.⁹ In addition, numerous studies have observed an association between lower wealth or more generally, lower socioeconomic status and diarrhea.⁹

Less clear is the association between wealth and infectious diarrhea in people living in low-income settings. Recent studies have suggested that inequalities in wealth among the very poor have important implications for health.^{10,11} If uncovered, such associations could potentially lead to more targeted efforts to reduce the burden of diarrheal illness.

The association between wealth and specific enteric pathogens is largely unknown, because studies of diarrhea often do not identify the specific pathogenic microorganism. Those that include such data have been limited in their ability to study the association of wealth and enteric pathogens.

Wealth can be evaluated through indices using household characteristics and asset data such as those collected by the Demographic and Health Survey (DHS). Because these indices are not based on income or expenditure data, they are considered proxies for economic rather than financial status.

A generally accepted method for constructing wealth indices is principal component analysis (PCA), a multivariate statistical technique used to reduce the number of variables in a dataset into a smaller number of dimensions. In PCA, a set of orthogonal vectors is created from linear combinations of the

underlying asset variables and ranked by the amount of variation in the original dataset that they capture. The vector that explains the most amount of the variation can be used as the wealth index and used to differentiate overall wealth among study participants, where lower (even negative) values indicate less wealth and vice versa. However, PCA-derived indexes do not have specific units or extrinsic value. Thus, the analyses to detect differences within a population usually divide it into wealth percentiles.

Using household data to construct a wealth index and data from pediatric studies on diarrhea and enteric parasite surveillance, we aimed to assess the association between wealth and enteric parasitic infections with *Giardia intestinalis* (syn. *G. duodenalis* and *G. lamblia*), *Cryptosporidium* spp., *Cyclospora cayetanensis*, and microsporidia in a low-income, periurban community in Peru.

METHODS

Study area. Pampas de San Juan de Miraflores is a periurban community of approximately 40,000 residents located 25 km south of the center of Lima, Peru. The area was largely settled in the late 1970s; after a highly transitional period, the population has stabilized, and the general living conditions have improved. Pampas de San Juan is built around a cluster of sandy hills. The early settlers lived in the lower areas, and their houses are the better built (bricks and concrete) and have better access to paved roads. More recent settlers usually settle in the higher parts of the hills, and their houses are constructed with wooden poles, cane shoots, plywood, and tin roofs. By 1995, 97% of houses reported having electricity, whereas 48% had toilets and 64% had potable water connection (Asociación Benéfica Proyectos en Informática, Salud, Medicina y Agricultura, Lima, Peru, unpublished data). Although reliable estimates of socioeconomic status are not available, the entire community is considered low income, although not uniformly.

Participants. The analysis used data from two consecutive longitudinal pediatric cohort studies conducted from December 1, 2001 to June 30, 2006. After an initial census of the site, children under the age of 12 years (the youngest in each household was used) living in Pampas were enrolled in

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the cohorts until the target sample size was reached. Children that became ill or had diarrhea during their participation in the study were referred to the local health post for medical care. Data from those visits were not part of this study.

Collection methods. Field workers visited the participants at their homes daily and collected data on diarrheal symptoms, including number and consistency of stools. Stool specimens were collected weekly from all children. Additional samples were collected on the first day of a diarrheal episode and daily until turning negative (participants who had *Cryptosporidium* or *Cyclospora*).

Stool specimens were kept in coolers with icepacks and transported to the laboratory every afternoon. Each specimen was processed by a standard ether concentration procedure and examined microscopically. Direct observation was used to identify *G. intestinalis*. *Cryptosporidium* spp. was identified using a modified acid-fast Ziehl-Neelsen stain. *C. cayetanensis* was identified by direct examination of wet mounts followed by epifluorescence to confirm autofluorescence, and microsporidia was identified using the Weber-modified Chromotrope stain. This work was performed in the parasitology laboratory of the Universidad Peruana Cayetano Heredia.^{12,13}

After enrollment, the study field workers conducted a thorough socioeconomic questionnaire that had 48 socioeconomic variables, including type of housing, sanitary facilities, water source, parental education, and presence of animals. Data on household characteristics reflected those surveyed by DHS, which were adapted to local conditions.

Analytical procedures. Dependent variables. We defined a day with diarrhea as a 24-hour period during which the child was reported to have three or more liquid or semiliquid stools. An episode of diarrhea was considered to end when the child had at least 3 consecutive days without diarrhea. We also defined persistent diarrhea when an episode lasted 14 days or longer. An episode of cryptosporidiosis, cyclosporiasis, microsporidiosis, or giardiasis was defined by one or more stool specimens positive for the respective parasite. We used two definitions for end of episode. For *Cryptosporidium*, *Cyclospora*, and microsporidia, an episode ended on the last day of microscopic parasite detection that was followed by at least three consecutive negative stools. For giardiasis, the end of an infection was the date of the last positive stool that was followed by three negative stools collected over a span of at least 21 days. Persistent infection was defined as an episode that had more than 14 days of stool positivity. An episode of infection was associated with diarrhea if this symptom occurred 1 week before, during, or 1 week after the infection episode.

Wealth index. To construct a relative index of socioeconomic status, we combined household-level information on assets using PCA to define the summed weights.¹⁴ The index is the first principal component, because it summarizes the largest amount of information common to the asset variables. The socioeconomic status score could only be calculated for children with complete data for all the components; therefore, children with missing data for any component of the score had a missing score value in that field.

The following variables were included in the wealth index: assets pertaining to size of the house ($N = 4$), quality of the house ($N = 17$), and possessions of furniture or appliances in the house ($N = 13$) (Table 1). Twelve variables were excluded, because they were either too abundant ($> 90\%$) or too scarce

($< 10\%$). The questionnaires captured continuous or categorical data. The variables that were measured continuously were area of the house, area of the roof, and number of rooms, bedrooms, windows, and doors. The number of rooms and number of bedrooms were divided by the number of persons, which has been done in other studies.¹⁵

Among the categorical variables describing the quality of housing materials, some were recoded into groups based on their relative costs. For example, households that reported disposing garbage either in the field, sewer, or burying it underground were recoded as low-cost garbage disposal, whereas households that had paid garbage collection services were recoded as high-cost garbage disposal.

Covariates. Covariates were selected based on biologic plausibility and literature review, and they included age, sex, number of other children under 5 years living in the same household, access to running water and toilet, ownership of home, ownership of animals discriminating between pets (mammals, birds, or others) and farm animals (livestock and poultry), and number of years of education of the mother and the father (1 if completed 12 years of education).

Statistical analysis. For the analysis, we included data from participants who had at least 80% compliance with study procedures and ≥ 6 months of participation in the study. Statistics were calculated with Intercooled Stata for Windows, version 8.2 (StataCorp., College Station, TX). The PCA module was used for the construction of the wealth indexes (WI), which were determined for each participant. The assigned WI value was used to categorize participants into tertiles representing the lower, middle, and upper one-thirds of WI values in the study population. Standard logistic regressions were run using the WI and one or more covariates clustering samples by child to allow for within-child correlations. Relative risks were assessed for significance by the χ^2 test. All statistical results were evaluated at the 0.05 level of significance.

The study protocols that collected data used in these analyses were approved by the institutional review boards of Asociacion Benefica Prisma, University of Georgia, The Johns Hopkins University, and the Centers for Disease Control and Prevention.

RESULTS

Of 534 participants enrolled in these cohorts, 492 (93%) had evaluable data (239 males and 253 females), with a mean age of 3.43 years and a range of 0–12 years. Participants were followed for a mean of 993 days (2.72 years), with a range of 187–1,643 days, for a total of 1,162.5 child-years (424,322 child-days) of surveillance. There were a total of 2,945 episodes of diarrhea, and 520 episodes (17.7%) were associated with positive stool diagnosis for one of the four enteric pathogens studied. Conversely, of the 2,024 infections identified, 25.7% were associated with diarrhea.

The burden of diarrhea in our study population averaged 2.5 episodes of diarrhea per 1 child per year, which is consistent with reported estimates of global disease burden.¹ The number of infection episodes of *Giardia* ($N = 1,475$) was greater than those of microsporidia ($N = 72$), *Cryptosporidium* ($N = 207$), and *Cyclospora* ($N = 270$). Meanwhile, the rates of diarrhea-associated infection per parasite ranged between 22% among children with microsporidiosis and 46% of participants with cryptosporidiosis (Table 2).

TABLE 1
Assets used in construction of wealth index, weights, and means by tertile

Asset category variable	Wealth index weight	Tertiles within this low-income community* (mean wealth index)		
		Low (−3.52)	Middle (0.66)	High (2.93)
Size				
Area of house (m²)	0.15	97.07	119.43	137.45
Roof area (m²)	0.20	46.96	62.73	96.80
Number of bedrooms/person	0.18	0.50	0.62	1.03
Number of rooms/person	0.15	0.24	0.27	0.44
Number of windows	0.24	0.74	1.64	3.84
Number of doors	0.24	1.92	3.41	5.66
Quality				
Running water in house	0.27	15%	84%	99%
Running water outside house	−0.01	14%	18%	9%
Other sources of water	−0.26	71%	4%	0%
Flush toilet	0.28	25%	96%	100%
Other sanitation	−0.24	58%	3%	0%
Garbage collection	0.18	65%	96%	98%
Other garbage disposal	−0.17	49%	12%	5%
High-quality wall material	0.27	13%	82%	99%
Medium-quality wall material	−0.07	21%	12%	4%
Low-quality wall material	−0.21	64%	17%	3%
High-quality floor material	0.22	48%	97%	100%
Low-quality floor material	−0.19	62%	22%	8%
High-quality roof material	0.22	2%	32%	79%
Medium-quality roof material	−0.10	43%	28%	7%
High-quality energy	0.11	63%	75%	94%
Medium-quality energy	−0.07	48%	41%	26%
Adequate ventilation	0.22	23%	68%	91%
Possessions				
Chairs	0.07	76%	86%	95%
Sofa	0.12	14%	32%	54%
Stools	−0.02	51%	50%	41%
Closet*	0.05	12%	22%	23%
Dresser	0.09	43%	59%	70%
Refrigerator	0.13	32%	43%	74%
Blender	0.11	46%	63%	77%
Gas stove	0.13	65%	80%	98%
Kerosene stove	−0.01	53%	52%	47%
Radio	0.06	73%	84%	86%
TV set, black and white	−0.04	49%	44%	33%
TV, color	0.08	46%	57%	75%
Stereo sound system	0.05	8%	11%	18%

* Indicates the percentage of people in the tertile that have such asset.

To better discriminate wealth within this low-income setting, the resulting WI was used to categorize each participant into low, medium, and high tertiles, with mean score of the first principal component of -3.52 (37% of households), 0.66 (31%), and 2.93 (32%), respectively. The first principal component explained 23% of the variability in the 36 variables and gave greatest weight to high-cost waste disposal (0.28), high-cost water infrastructure (0.27), low-cost water infrastructure (-0.26), and number of windows (0.24). A summary of all the variables is presented in Table 1. The first three eigenvalues (vectors of same direction of the principal component but with different magnitude) were 8.22, 3.15, and 2.00 and accounted for 23%, 9%, and 6% of the variation, respectively.

TABLE 2

Number of episodes of infection in a low-income community

Infections by wealth	Microsporidia	Cyclospora	Cryptosporidium	Giardia
Low tertile	39 (54%)	111 (41%)	73 (35%)	743 (50%)
Middle tertile	18 (25%)	81 (30%)	77 (37%)	423 (29%)
High tertile	15 (21%)	78 (29%)	57 (28%)	309 (21%)
Total	72	270	207	1,475
Infections associated with diarrhea	23 (32%)	70 (26%)	96 (46%)	331 (22%)

Incidence rates were calculated by dividing the number of infections by the number of days in surveillance. The incidence rates of diarrhea were uniform across tertiles of relative wealth (Table 3). However, the incidence rates of parasitic infections were not. *Giardia* infections decreased with increasing wealth as well as their diarrhea-associated infections. Although not statistically significant, the rates of microsporidia decreased with higher tertiles of wealth. Interestingly, the rates of *Cyclospora* and *Cryptosporidium* infections were unrelated to relative wealth.

After multivariate analysis, wealth remained inversely associated with the rates of giardiasis (Table 4). The protective effect of wealth on microsporidia infection became statistically significant in multivariate analysis. Both *Cyclospora* and *Cryptosporidium* remained unassociated with relative wealth.

The analysis of wealth and its association with length of infections showed that persistent giardiasis (lasting more than 14 days) was also associated with lower tertiles of wealth (Table 5). The effect of increased wealth on microsporidia showed a trend, although not statistically significant, to protection against persistent microsporidiosis.

The analysis of covariates for their associations with parasitic infections showed that older age was protective against

TABLE 3
Incidence of diarrhea, infection, and symptomatic infection by tertile

	Incidence of episodes per child-day in a low-income community (number of episodes/424,322 child-days of diarrhea surveillance)			P
	Low tertile	Middle tertile	High tertile	
Diarrhea	0.00609	0.00634	0.00556	0.45
Infections with parasites				
Microsporidia	0.00020	0.00012	0.00010	0.06
<i>Cyclospora</i>	0.00058	0.00054	0.00054	0.87
<i>Cryptosporidium</i>	0.00038	0.00051	0.00040	0.21
<i>Giardia</i>	0.00389	0.00282	0.00215	< 0.01
Infections with associated diarrhea				
Microsporidia	0.00006	0.00027	0.00056	0.39
<i>Cyclospora</i>	0.00020	0.00021	0.00017	0.73
<i>Cryptosporidium</i>	0.00015	0.00019	0.00084	0.08
<i>Giardia</i>	0.00091	0.00062	0.00043	< 0.01

diarrhea, microsporidia, *Cyclospora*, and *Cryptosporidium* (data not shown). Older age was not protective against *Giardia* infections but was protective for giardiasis with associated diarrhea. Having children under age 5 in the home was a risk factor for diarrhea and *Giardia* infection. No differences were found between sex of the participants and maternal or paternal education.

DISCUSSION

We assessed the overall socioeconomic status using a WI of household assets weighted using PCA. Unlike income or expenditure data, this information can be more easily and reliably obtained, especially in settings where income varies temporally, may not always be in currency, and is reluctantly reported.¹⁶ This method of weighing assets has been validated in studies that show that it is a better measure of socioeconomic status than income or education.^{16,17} Furthermore, the method of PCA has been well-described and is becoming the standard tool for constructing wealth indices.^{11,15,18}

In this study, PCA allowed us to assess if differences in wealth within a low-income community had any effects on the rates of diarrhea and parasitic infections, which have been associated with lower socioeconomic status. Although diarrhea is more prevalent in economically disadvantaged groups

TABLE 4
Odds ratio (OR) for rates of diarrhea, infection, and symptomatic infection compared with the low tertile in a low-income community (univariate and multivariate analysis)

	Middle tertile		High tertile	
	OR (univariate)	OR (multivariate)	OR (univariate)	OR (multivariate)
Diarrhea	1.04	0.92	0.91	0.85
Infections with parasites				
Microsporidia	0.59	0.480*	0.51	0.458*
<i>Cyclospora</i>	0.93	0.92	0.93	0.96
<i>Cryptosporidium</i>	1.34	1.55	1.04	1.27
<i>Giardia</i>	0.725†	0.651†	0.551†	0.551†
Infections with associated diarrhea				
Microsporidia	0.46	0.175†	0.97	0.399*
<i>Cyclospora</i>	1.05	0.84	0.85	0.70
<i>Cryptosporidium</i>	1.27	1.49	0.57	0.71
<i>Giardia</i>	0.681†	0.69	0.473†	0.562*

* Significant at $P = 0.05$.

† Significant at $P = 0.01$.

TABLE 5
Unadjusted OR for rates of persistent infection (F test compared with the low tertile)

	Middle	High	P value
Microsporidia	0.637	0.266	0.20
<i>Cyclospora</i>	1.073	0.664	0.16
<i>Cryptosporidium</i>	5.098*	2.656	0.10
<i>Giardia</i>	0.670*	0.473*	< 0.01

* Significant at $P = 0.05$.

when studied across populations, within our study, population relative differences in wealth were not associated with differential rates of diarrhea. This finding may be explained by the relative homogeneity of our study population compared with larger studies with more diverse populations that may be subject to confounding. Alternatively, it may suggest that only differences in wealth larger than that found in a low-income setting are associated with diarrhea.

Relative greater wealth was protective for *Giardia* infections in general as well as diarrhea-associated giardiasis and persistent infections with *Giardia*, even after adjusting for established risk factors. Wealth was in fact two times as protective for *Giardia*, because it not only was associated with a lower risk of infection but also for an infection to become persistent (data not shown). Similarly, greater wealth was also protective against microsporidia infections. Interestingly, this analysis showed no association between wealth and infections with *Cyclospora* or *Cryptosporidium*.

The analysis of covariates confirmed previous observations that age plays a role in the frequency of infections with *Cryptosporidium*, *Cyclospora*, and microsporidia but was not associated with the frequency of giardiasis. Although these differences have been previously reported, the exact mechanisms for these differences by age are not yet fully understood, and studies with strong epidemiological and immunological designs are needed to properly address this question.

These results may have important implications on our understanding of the epidemiology and pathogenesis of these enteric parasites. It may well be that wealth as a measure in our study was also a surrogate for other factors, such as nutritional status. This is well-established risk factor for illness in general and was not part of this study. Other factors not measured were health education and sanitation practices within the household,¹⁹ which also have an effect on the frequency of infectious diseases. Additionally, wealth could be a marker for a family's ability to respond to new hardships. A less poor family may be better able to procure alternative sources of water if it becomes scarce or still afford basic necessities (water, food, soap, etc.) if there were abrupt changes that could temporarily affect the economic status of the household. This may not happen with families in the lowest tertile.

Our study has limitations worth considering. Although wealth indices have become an accepted tool in the literature, they also have limitations.²⁰ Indices vary with the assets included and therefore, are subject to study design or bias. In our study, we used a large and varied group of assets and ran the analysis multiple times using different indices (data not shown) to verify the consistency of results. Also, the explanatory power of the wealth index may be confounded by the inclusion of direct and indirect determinants of health; although access to running water suggests increased wealth, it may also reduce the transmission of infectious diseases. We took this fact into

account and included running water and other potential confounders in the multivariate analysis. Additionally and as mentioned in the introduction, the constructed wealth indexes are dimensionless and do not have extrinsic values; thus, wealth indices from two different communities or even studies within the same community may not be compared or combined.

Our study may also be affected by case definitions. We used generally accepted definitions for episodes of diarrhea and enteric infections. However, we used a study-specific definition to determine an episode of *Giardia* infection, primarily because of the lack of a standardized definition. Our definition might have under- or overrepresented the real infection rates in this study. This analysis also highlights the existing challenges inherent to determining the endpoint of an episode of *Giardia* infection in endemic settings, where most infections are asymptomatic. In addition, we found a large proportion of cases of parasitic infection without diarrhea, suggesting that our case definition of diarrhea may have lacked sensitivity.

To our knowledge, this is the first study to explore the association of wealth with specific enteric causes of infectious diarrhea. Our analysis suggests that, beyond the known risk factors, poorer individuals within already impoverished settings face a different burden of infections; *Giardia* and microsporidia are more frequent among the poorest, whereas *Cryptosporidium* and *Cyclospora* were not affected by these variations in socioeconomic status.

Our study provides further evidence that, within already impoverished settings, relative differences in wealth can have important implications on health. This suggests that, in the face of limited resources, targeted interventions focused on poorer subpopulations within low-income settings may have more favorable results. Assessment of relative wealth using household characteristics, which can be done quickly and reliably, may provide an impartial method for such targeting efforts.

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