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The Co-occurrence of Anemia and Stunting in Young Children

by

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B.A., Auburn University, 2012

Thesis Committee

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An abstract of a thesis submitted to the faculty of the Rollins School of Public Health of Emory University in partial fulfillment of the requirements for the degree of
Master of Public Health
Hubert Department of Global Health

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ABSTRACT

The Co-occurrence of Anemia and Stunting in Young Children

Background and objectives: Anemia and stunting are prevalent nutritional problems among children of low- and middle-income countries that have profound effects on child development, morbidity, and mortality. A single conceptual framework is used often to identify the basic determinants of these and other forms of malnutrition. One would expect that problems with matching underlying determinants should co-occur in effected communities and individuals to a greater degree than by chance. We know from ecological analyses that stunting and anemia cluster across types of countries and their regions but is this also the case at the level of individuals, a question seldom asked and which we address.

Methods: In two separate populations of children – ages 6-18 months in Bihar, India (n=5664) and 0-36 months in Lambayeque, Peru (n=840) – we measured the frequency of the co-occurrence of anemia and stunting. We compared this value to the value expected by chance, the product of the prevalence of anemia and stunting using a chi-square test. Using an iterative model selection process, we built explanatory logistic regression models for each condition.

Results: The frequency of co-occurrence in the Indian population was 21.5%, and in the Peruvian population it was 27.1%, which are similar to frequencies expected by chance, 21.3% (p=0.97) and 28.0% (p=0.87) respectively. In both populations, anemia was associated with sex, while stunting was associated with age, sex, wealth, and social standing (caste or indigenous). In the Peruvian population, anemia was also associated with age, while stunting was associated with dietary diversity over the past month. In the Indian population, anemia was also associated with caste, dietary diversity over one day, and household hunger, while stunting was associated with maternal illiteracy

Conclusion: There was no statistically significant difference in the co-occurrence of anemia and stunting compared to what was expected by chance. Despite some basic shared factors (sex, age, caste), anemia and stunting appear are more independent than commonly assumed.

Implications: Anemia and stunting should be treated as independent and addressed according to their context-specific causes. Additional research into these context-specific determinants is needed.

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Table of Contents

LITERATURE REVIEW

Global Burden of Anemia and Stunting

Affecting 273.2 million children ages 6 – 59 months worldwide and as many as 6 in 10 children in low and middle-income countries (LMIC), anemia is a widespread problem with consequences that extend beyond low hemoglobin concentration[1]. Anemia in children 6 – 59 months of age at sea level is defined by a blood hemoglobin concentration lower than 11 g/dL[2]. There are many forms of anemia; however they can be grouped into two broad categories: nutritional anemia and anemia caused by disease or disorder[3]. Iron deficiency anemia (IDA) is thought to be the most common form of anemia, although the exact proportion attributable to IDA is unclear and can vary widely from <1% to 75% depending on region and country[1,4,5]. IDA is associated with negative impacts on brain function, metabolism, and immune function in children[6-8]. Effects of anemia also include reduced mental capacity, delayed motor development, poor educational attainment, and reduced economic output[3,9]. In fact IDA alone is responsible for an estimated loss of over 51 million disability-adjusted life-years[10], and approximately US$3.82 per capita in economic losses are attributed to the decrease in physical and cognitive productivity caused by anemia[11]. Full-term infants are born with iron stores to support their needs until 4-6 months of age after which iron must be consumed from the diet[12]. This time between ages 1 and 2 years presents the highest risk of anemia after which it declines until menarche for girls[13]. Evidence supports supplementation, fortification, and treatment of anemia-related diseases to combat anemia[14]. Despite efforts to address it, the prevalence of anemia remains high in India and in Peru[1,15]. In Bihar, India 63.5% of children ages 6 – 59 months have anemia[16]. In Lambayeque, Peru the prevalence of anemia in children 6-59 months is 36%[17].

Stunting, an indicator of chronic malnutrition, affects 159 million children under 5 globally, and LMIC, bearing a disproportionate burden of the condition, account for over 90% of the world's stunted children[18]. Stunting is defined as linear growth faltering that leads to a child measuring less than two standard deviations below the mean length or height of a reference population of the same age, preferably the World Health Organization reference population[19]. Stunting is associated with child morbidity, mortality, reduced cognition, and decreased educational attainment[20-23]. The World Bank estimated that stunting reduces a person's lifetime earning by 10%[14]. The evidence for nutrition-specific interventions that target immediate causes of stunting is much stronger than the evidence for nutrition-sensitive programs that target more fundamental or underlying causes[24]. However, there is strong evidence that the largest risk factors for stunting are fetal growth restriction, preterm birth and environmental hazards (i.e. unimproved sanitation) [25]. Stunting develops during the first 1,000 days of life beginning at conception. The effects of stunting are most likely irreversible after this period. Like most LMIC, India and Peru continue to bear a high burden of stunting in states like Bihar where the prevalence of stunting in children is 48.3%[16] and Lambayeque where 14.1% of children 6-59 months are stunted[17].

Dual Burden of Malnutrition

The oft-cited UNICEF Conceptual Framework for the Causes of Malnutrition shows the relationship between the underlying determinants of malnutrition including the availability, accessibility, and use of resources and the immediate causes of malnutrition[26].

The framework depicts shared causes at the population, household, and individual level for all types of malnutrition. The conceptual framework for anemia by the World Bank Group and other frameworks for malnutrition are built upon these same causes[24]. If micronutrient deficiencies and growth faltering share the basic causes, then an efficient use of resources would target the shared causes to eliminate various forms of malnutrition simultaneously. Under the shared causes assumption, interventions could identify participants using one indicator of malnutrition such as anemia rather than measuring children for various forms of malnutrition.

Country-level analyses show that low and middle-income countries (LMIC) share a higher burden of malnutrition, including anemia and stunting, than high-income countries[18]. This clustering of anemia and stunting at the country level is consistent with clusters of need and unequal distribution of resources[27,28]. Clustering of the conditions also occurs regionally[15,29]. Clustering of malnutrition has led to the adoption of the term "double burden" or "dual burden" to signify the co-occurrence of two or more nutritional issues[30]. However, studies that focus on the existence of the multiple forms of malnutrition within populations are ecological in nature, reveal nothing about their joint distribution, and may lead to false conclusions about their co-occurrence in individuals[31]. In Latin America, an increasing prevalence of overweight and obese adults and a high prevalence of child malnutrition led to a flurry of research into this dual burden at the national, community, and household level[32-35]. This research found that the dual burden of malnourished children with overweight or obese mothers did not co-occur at a frequency of public health significance above what was expected due to chance[36]. Further research found that the dual burden of child stunting and maternal overweight/obesity was a "statistical artifact"[37].

While it is certain that some populations bear a higher burden of both conditions, it is unclear that the co-occurrence of anemia and stunting affects children at a higher frequency than would be expected by chance. If anemia and stunting co-occur because of their shared basic and underlying causes, we would expect to observe the conditions in the individuals who bear those determinants and at a higher prevalence than what is expected by chance. Few studies, mostly in Latin America, have examined the co-occurrence of anemia and stunting[38], and even fewer have compared the observed values to what is expected by chance[39,40]. Results of these studies concluded that the frequency of co-occurring anemia and stunting was not meaningfully higher than what one would expect by chance and conclude that the two conditions should be treated as independent[39,40]. No currently available studies have combined analysis of the co-occurrence of the two conditions with context-specific explanatory models of the underlying determinants of anemia and stunting in young children.

The question that inspires this research is whether anemia and stunting share underlying determinants that produce both forms of malnutrition in the same individuals, and whether targeting a population's young children who have one nutritional deficiency such as anemia also capture the children who are affected by another form of malnutrition such as stunting. This study has two specific aims: 1) to determine whether the co-occurrence of anemia and stunting occurs more frequently than would be expected by chance and 2) to compare and contrast the key determinants of anemia and stunting in two contexts. We accomplished these aims through a secondary data analysis in a population of

5,664 young children (6-18 months) in Bihar, India and another population of 840 young children (0-36 months) in Lambayeque, Peru.

METHODS

Sample

We used data from two previous cross-sectional studies. Both samples were randomly selected using a multi-stage cluster probability proportional to size design. Seventy health-sub centers treated as clusters were selected randomly from a single district in Bihar, India as part of a home fortification randomized effectiveness trial[41]. A sample of 5664 children were selected from a listing of children 6-18 months of age residing in randomly selected villages within the assigned health-sub center. One hundred sixty villages were selected randomly from four districts in Lambayeque, Peru as part of a baseline cross-sectional study. A sample of 840 children were drawn from a listing of children 0-36 months residing in the selected villages.

We determined the prevalence of anemia defined as blood hemoglobin concentration <11 g/dL adjusted for elevation[42,43] and stunting defined as length or height-for-age <2SD of the WHO reference population[44]. Hemoglobin was measured in the household by finger-stick using a Hemocue beta-hemoglobin test (Ängelholm, Sweden). Length was measured on children under 18 months and height on older children using standard anthropometric techniques. Weight was assessed with the Seca 874 digital scale [Seca, Hamburg, Germany] and length with the Seca 417 mobile infantometer. We measured mid-upper arm circumference (MUAC) with MUAC tapes (S0145620 MUAC, Child 11.5 Red/PAC-50). Length/height-for-age z-scores were calculated using the WHO

Anthro SAS macro[45]. Enumerators administered household surveys of basic demographics, health, and nutrition. Maternal youth at marriage was defined as being married at 18 years or younger. A wealth index was created using principal components analysis and households were ranked into tertiles. Infant and young child feeding practices were defined in accordance with the WHO guidelines[46]. IYCF indicators included proportion currently breastfeeding, timely introduction of complementary foods (between 6-7 months of age), minimum dietary diversity (≥4 different food groups), and minimum meal frequency (2 times/day for breastfed infants 6–8 months, 3 times/day for breastfed children 9–23 months, 4 times/day for non-breastfed children 6–23 months). Dietary diversity was assessed differently for the Peruvian sample over the previous 7 days using a food frequency questionnaire rather that the 24-hour dietary diversity scale used in the Indian study. Household hunger was assessed in the Indian sample using the Household Hunger Scale and dichotomized into 0 and ≥1[47], while the Household Food Insecurity Access Scale occurrence question were used in the Peruvian sample and dichotomized into ≤3 and >3[48]. There was not a true measure of parity in the Peruvian population since the number of births was measured for only the previous 3 years. This was used a proxy for birth spacing rather than actual parity. Caste is widely recognized as a measure of social status in India, and similarly Quechua-speaking populations (indigenous populations) have a lower social status in Peru. We did not include these variables in the wealth index as measures of socio-economic status but rather left them as independent measures. Although other backward caste (OBC) was the largest social stratum, we avoided using it as the reference group for analysis since it is likely the most heterogeneous. It is composed of many different minority castes with varying social standing. We opted to use scheduled caste as the reference group due to the homogeneity and standing as the lowest caste in this context[49].

Analytic Strategy

Contingency tables were generated for each country to determine the observed frequency of co-occurrence of anemia and stunting defined as having both conditions at the time of measurement. The prevalence of each condition was calculated separately and for each country. The product of the prevalence of anemia and stunting was considered the expected frequency of co-occurrence. The squared difference of the observed and expected frequencies of co-occurrence divided by the expected was the chi-squared statistic with one degree of freedom. A priori alpha-level was set at 0.05. Hypothesizing that the relationships between anemia/stunting and age might affect the joint relationship, we stratified this analysis by age.

For explanatory modeling, we first examined the bivariate relationships between household and individual factors available from the surveys and anemia. We repeated the process for stunting. Using an iterative model selection process, we built explanatory multiple logistic regression models for anemia and stunting using variables that had a bivariate association with the corresponding independent variable. The model was reduced to include only associated and confounding variables. Confounding was assessed by two criteria: plausibility and a change in the point estimates of other variables by 10% or more upon the confounder's addition or removal. In all regression analyses we accounted for the sampling design using SAS survey procedures. Alpha-level for regression analysis was 0.05. We used variance inflation factor to test for multi-colinearity among our independent variables. The Internal Review Boards (IRB) of the Instituto de Investigación Nutricional

(IIN) and Emory University approved the original studies and exempted the secondary data analysis from further review.

RESULTS

The Indian sample was 49% female with a mean age of 11.4 months. The mean age of mothers was 25.1 years, most were illiterate (57.1%), and 22.5% belonged to a scheduled caste. The prevalence of anemia in the Indian sample was 68.8% with a mean hemoglobin concentration of 10.2 g/dL. The prevalence of stunting was 31% with a mean length-for-age z-score of -1.4 (Table 1). The Peruvian sample was 48.1% female with a mean age of 15.7 months. The mean maternal age was 28.9 years, few were illiterate (11.2%), and 8.1% spoke only Quechua and not Spanish. The prevalence of anemia in the Peruvian sample was 72.3% with a mean hemoglobin concentration of 10.2 g/dL. The prevalence of stunting was 38.7% with a mean height-for-age z-score of -1.6 (Table 1).

Co-occurrence in a child was defined as having both anemia and stunting at the time of measurement. The observed frequency of co-occurrence was 21.5% among the Indian children and 27.1% among the Peruvian children. The expected frequency of co-occurrence by chance was 21.3% in the sample of Indian children and 28.0% in the sample of Peruvian children. There was no statistically significant difference between the observed frequency of co-occurrence and the expected frequency. These results were stratified by age, and we found no differences between the observed and expected frequencies of co-occurrence (Table 2).

Table 1: Basic characteristics and nutritional status

Variable	India (n=5678)	Peru (n=840)
Age, months	11.4 ± 3.4	15.7 ± 9.7
Female	49	48.1
Maternal age, years	25.1 ± 4.7	28.9 ± 8.6
Maternal illiteracy	57.1	11.2
Maternal youth at marriage (<18 years)	60.3	-
Scheduled caste	22.5	-
Scheduled tribe	9.1	-
Other backward caste	54.5	-
Other caste/outside the caste system	13.9	-
Quechua-speaking	-	8.1
Minimum dietary diversity score[1]	29.8	73.6
Age-appropriate quantity of food	4.5	-
Household hunger[1]	6.6	27.4
Diarrhea in previous two weeks	12.6	31.3
Hospitalization in previous two weeks	0.8	-
Fever in previous two weeks	50.5	39.5
Symptoms of pneumonia	34.0	48.8
Parity[2]	2.7 ± 1.6	1.2 ± 0.4
Hemoglobin (Hb), g/dL	10.2 ± 1.5	10.2 ± 1.3
Anemia (Hb < 11 g/dL)	68.8	72.3
Height-for-age z-score	-1.4 ± 1.2	-1.6 ± 1.2
Stunting (≤ -2SD ht/age)	31	38.7

Note: Values are means ± SD or %.
[1]Minimum dietary diversity and household hunger are not directly comparable between the samples since different measurement instruments were used.
[2]Parity in the Peruvian sample is a measure of children born to the mother only during the previous 3 years.

Table 2: Comparison of the observed co-occurrence of anemia and stunting to the expected chance co-occurrence

Population	Observed co-occurrence (%)	Expected co-occurrence (%)	χ^2	p
India	**21.5**	**21.3**	**0.001**	**0.97**
6-12 mo	14.9	14.9	0.000	>0.99
13-18 mo	27.9	27.8	0.036	0.85
Peru	**27.1**	**28.0**	**0.028**	**0.87**
0-5 mo	12.5	10.5	0.38	0.54
6-12 mo	24.5	24.7	0.16	0.69
13-18 mo	34.7	33.5	0.0004	0.98
19-36 mo	32.2	32.1	0.0003	0.99

Among the Indian children, statistically significant bivariate relationships exist between anemia and the following variables: sex, caste, dietary diversity, and household hunger. Bivariate relationships with stunting include child age, sex, maternal youth at marriage, maternal illiteracy, caste, wealth tertile, age appropriate quantity of food consumed, parity, and prevalence of diarrhea, fever, and symptoms of pneumonia. Among the Peruvian children statistically significant bivariate relationships exist between anemia and the variables child's age and wealth tertile. Stunting in the Peruvian sample is associated with child's age, child sex, maternal illiteracy, wealth tertile, dietary diversity, language spoken, parity, and prevalence of fever (Table 3). Other variables not associated with either outcome include religion, mother's age, meal frequency, currently breastfeeding, and timely introduction of complementary foods.

Table 3: Bivariate association between nutritional deficiencies and related variables

	India, OR (95% CL)		Peru, OR (95% CL)	
Variable	**Anemia**	**Stunting**	**Anemia**	**Stunting**
Child's age in months	1.02 (0.99, 1.04)	**1.15 (1.13, 1.17)**	**0.95 (0.93, 0.97)**	**1.07 (1.06, 1.09)**
Female child	**0.78 (0.70, 0.87)**	**0.78 (0.69, 0.88)**	0.92 (0.69, 1.22)	**0.71 (0.53, 0.95)**
Maternal youth at marriage	1.02 (0.89, 1.16)	**1.41 (1.26, 1.59)**	-	-
Maternal illiteracy	1.02 (0.90, 1.16)	**1.89 (1.67, 2.13)**	0.83 (0.50, 1.36)	**1.58 (1.05, 2.39)**
Schedule caste	**ref**	**ref**	-	-
Scheduled tribe	1.16 (0.86, 1.57)	**0.54 (0.44, 0.67)**	-	-
Other backward caste	**0.75 (0.62, 0.91)**	**0.54 (0.43, 0.68)**	-	-
Other caste	**0.67 (0.59, 0.77)**	**0.72 (0.62, 0.82)**	-	-
Highest wealth tertile	**ref**	**ref**	**ref**	**ref**
Lowest wealth tertile	1.17 (0.97, 1.40)	**2.23 (1.94, 2.58)**	1.16 (0.78, 1.72)	**2.43 (1.64, 3.61)**
Middle wealth tertile	1.03 (0.89, 1.18)	**1.78 (1.52, 2.08)**	**1.53 (1.03, 2.27)**	**1.78 (1.18, 2.68)**
Minimum dietary diversity[1]	**0.86 (0.74, 1.00)**	0.95 (0.84, 1.08)	0.73 (0.49, 1.07)	**0.60 (0.41, 0.88)**
Household hunger/food insecurity[2]	**1.47 (1.13, 1.91)**	1.14 (0.91, 1.44)	1.10 (0.77, 1.59)	1.22 (0.81, 1.83)
Age Appropriate Quantity of Food	1.06 (0.81 - 1.40)	**0.73 (0.56 - 0.96)**	-	-
Diarrhea (previous two weeks)	0.95 (0.78, 1.16)	**1.22 (1.01, 1.47)**	1.09 (0.79, 1.51)	1.00 (0.72, 1.40)
Fever (previous two weeks)	1.10 (0.96, 1.26)	**1.17 (1.03, 1.34)**	1.33 (0.99, 1.80)	**1.36 (1.00, 1.84)**
Symptoms of pneumonia	1.00 (0.84, 1.20)	**1.27 (1.03, 1.56)**	1.23 (0.92, 1.63)	1.32 (0.98, 1.78)
Parity[3]	0.98 (0.95, 1.02)	**1.11 (1.07, 1.16)**	1.20 (0.77, 1.86)	**0.53 (0.34, 0.83)**
Spanish-speaking	-	-	**ref**	**ref**
Quechua-speaking	-	-	1.21 (0.70, 2.11)	**2.91 (1.70, 4.99)**
Bilingual	-	-	1.72 (0.70, 4.19)	**2.66 (1.23, 5.75)**

Note: Statistically significant results ($p<0.05$) are bolded.
[1]Minimum dietary diversity assessed over 24 hours in Indian sample; 7 days in Peruvian sample.
[2]Household Hunger Scale used in Indian sample; Household Food Insecurity Access Scale in Peruvian.
[3]Parity in the Peruvian sample is a measure of children born to the mother in the previous 3 years.

Factors protective against anemia in a multiple logistic regression model of the Indian sample included being female, being in other backward caste or other caste rather relative to scheduled caste, and minimum dietary diversity. Household hunger was a risk factor for anemia. Factors protective against stunting in a multiple logistic regression model of the Indian sample included being female and being in scheduled tribe or other backward caste relative to scheduled caste. Risk factors for stunting included child's age in months, maternal illiteracy, and being in lowest or middle wealth tertile relative to the highest. In the model of stunting we also controlled for parity, prevalence of diarrheal disease, and whether the child consumed an age appropriate quantity of food because they were determined to be in a confounding relationship with other exposures (Table 4).

The multivariate models in the Peruvian samples show similar results. While age and sex are the only statistically significant variables associated with anemia in this model, the model shows the same direction of the relationship between dietary diversity and household food insecurity. In the model of stunting among the Peruvian sample, stunting was associated with age, sex, wealth, and being a Quechua speaker. We also controlled for prevalence of diarrhea (Table 4). We found no multi-colinearity among the variables in any of our models.

Table 4: Multivariate regression model of underlying variables associated with anemia and stunting

	India, aOR (95% CL)		Peru, aOR (95% CL)	
Variable	**Anemia**	**Stunting**	**Anemia**	**Stunting**
Child's age in months	-	**1.16 (1.13, 1.19)**	**0.93 (0.91, 0.95)**	**1.07 (1.04, 1.09)**
Being a female child	**0.78 (0.70, 0.87)**	**0.72 (0.60, 0.85)**	**1.02 (0.73, 1.43)**	**0.62 (0.44, 0.87)**
Maternal illiteracy	-	**1.44 (1.19, 1.74)**	-	-
Scheduled caste	**ref**	**ref**	-	-
Scheduled tribe	1.18 (0.88 – 1.6)	**0.49 (0.36, 0.67)**	-	-
Other backward caste	**0.76 (0.62, 0.93)**	**0.75 (0.59, 0.97)**	-	-
Other caste	**0.68 (0.59, 0.77)**	0.75 (0.53, 1.05)	-	-
Highest wealth tertile	**-**	**ref**	**ref**	**ref**
Lowest wealth tertile	-	**1.76 (1.41, 2.21)**	0.97 (0.61, 1.53)	**2.24 (1.38, 3.65)**
Middle wealth tertile	-	**1.54 (1.23, 1.93)**	**1.61 (1.02, 2.53)**	**1.73 (1.07, 2.80)**
Minimum dietary diversity[1]	**0.87 (0.75, 1.00)**	-	0.82 (0.53, 1.28)	**0.58 (0.37, 0.89)**
Household hunger/food insecurity[2]	**1.48 (1.14, 1.92)**	-	1.26 (0.83, 1.91)	-
Diarrhea prevalence	-	1.23 (0.96, 1.58)	-	1.04 (0.72, 1.51)
Age Appropriate Quantity of Food	-	0.88 (0.60, 1.28)	-	-
Parity	-	1.05 (0.99, 1.11)	-	-
Spanish-speaking	-	-	-	**ref**
Quechua-speaking	-	-	-	**2.46 (1.27, 4.73)**
Bilingual	-	-	-	2.32 (0.89, 6.06)

Note: Statistically significant results ($p<0.05$) are bolded.
[1]Minimum dietary diversity assessed over 24 hours in Indian sample; 7 days in Peruvian sample.
[2]Household Hunger Scale used in Indian sample; Household Food Insecurity Access Scale in Peruvian.

DISCUSSION

The UNICEF Conceptual Framework for the Causes of Malnutrition[26] is an important foundation for understanding how political, societal, economic, and household factors cause malnutrition; however, it fails to represent the complex ways in which these factors affect children differentially. As in previous studies[39,40], there was no meaningful difference in the co-occurrence of anemia and stunting compared to what was expected by chance suggesting that anemia and stunting are more independent than commonly assumed. While the two nutritional conditions shared some basic risk factors (sex, caste, and age), other economic, health, and household characteristics were differentially affected. Maternal characteristics and economic status were strongly associated with stunting but not with anemia, while food security and dietary diversity were associated with anemia but not stunting in the Indian sample of younger children. Dietary diversity was associated with stunting in the Peruvian sample of older children. This could be a result of the differential methods of measuring dietary diversity. It is important to note that socioeconomic status is a complex construct[50]. Here, social standing (caste or language spoken) is associated with both anemia and stunting, while wealth index, in the Indian sample, is associated only with stunting and household hunger is only associated with anemia. This may be explained by the vegetarian diet consumed by Indian children across economic strata that tends to be low in bioavailable iron[51]. We were concerned about issues of gender inequalities that disadvantage girls; however, we found that being female was consistently protective against anemia and stunting in this age group, consistent with other literature[13,52,53]. The most common hypothesis for this difference in anemia between sexes is the increased iron requirements in males due to rapid gains in muscle mass[54].

The lack of consensus in the literature on which determinants are associated with each condition may be related to the unique context, measures, or length of exposure in each study. Nonetheless, we can conclude from this study that these determinants are not equivalently causing anemia and stunting in these populations else they would be co-occurring.

While we aimed to study the determinants of anemia and stunting, the cross-sectional design limits the investigation to studying associated factors that are generally assumed to be determinants. Observational research does not permit us to study specific effects and cross-sectional studies are unable to establish temporality. However, we can make reasonable assumptions about the existence of some basic household characteristics such as socio-economic status and maternal characteristics prior to the occurrence of anemia and stunting. The co-occurrence of the two conditions might be affected by the etiology of anemia. While no genetic or infectious disease screening was conducted, this study shows that the relationship of the expected chance co-occurrence with the observed co-occurrence does not differ between the two distinct settings. As in all secondary data analyses, we were limited to the survey questions from each original study. Some of the questions such as caste and indigenous language were context-specific while others were simply not asked in one primary study but available in the other. Each of these cases made direct comparisons impossible. Due to the lack of some important questions and a much smaller sample size over a larger geographical area, there was reduced precision in the models of the Peruvian sample. Much smaller sample size in the Peruvian dataset contributed to a loss of precision in our regression estimates. This is an important consideration in the comparison of the models from each country. The models are presented to provide a comparison of the directionality of the association. We were also missing some key variables that have been important to stunting and anemia in other studies including maternal nutrition, birth weight, gestational age at birth, and other environmental indicators[3,25]. A prospective cohort study through the first 1,000 days of life that includes the aforementioned variables and biomarkers would be the ideal study design to reduce these limitations. The co-occurrence of additional forms of malnutrition should be examined in future research. Perhaps deficiencies in more closely related micronutrients would yield different results (e.g. iron and zinc); however, to date the available research has not examined these relationships.

This study builds upon our limited knowledge about the co-occurrence of different forms of infant malnutrition. We have shown that the frequency of co-occurrence is a function of their respective frequencies rather than shared determinants in two distinct contexts and across age strata. We showed evidence of an ecological fallacy: areas exhibiting a high prevalence of anemia and a high prevalence of stunting did not show evidence of a relationship between the two. Furthermore, we were able to show that there is no single determinant whose solution would end both anemia and stunting. However, models of the determinants measured by our surveys accounted for a small percentage of the variability in the outcomes. R-square values for the multivariate models of anemia in Peru and India are 8.5% and 1.4% respectively, and for stunting 11.7% and 8.4%.

IMPLICATIONS FOR PUBLIC HEALTH

The UNICEF Conceptual Framework for the Causes of Malnutrition is perhaps encompasses all of the determinants discussed and is perhaps too broad for considering which interventions will impact specific forms of malnutrition. Our research adds to the evidence that anemia and stunting should be treated as independent conditions. It must not be assumed that interventions that address an underlying determinant of anemia will have a complementary reduction in stunting. Targeting one condition would not identify or address the other condition simultaneously in these populations. Our design did not enable us to test specific interventions; however, it challenges us to consider the types of interventions that address the associated determinants. Stunting may be better addressed through targeting lower economic strata, while interventions spanning socio-economic strata may be needed to address anemia. While there is no single solution to both problems, interventions may not be mutually exclusive. We recommend the simultaneous targeting of the immediate and distal causes of malnutrition to have the greatest impact and address anemia and stunting. Income-generating activities, targeted supplementation, and equitable access to contraception may have a stronger impact on stunting, while staple food fortification and wide-reaching iron supplementation and IYCF education may better impact anemia. Income-generating interventions can improve the underlying determinants of stunting[55]. Supplementation with zinc can significantly increase mean gain in height[56], and public provision of complementary foods in food insecure settings can significantly reduce the odds of stunting in children[57]. There is evidence that unwanted and mistimed pregnancies are associated with increased odds of the child being stunted[58,59]. Mandated staple food fortification with iron significantly decreased anemia[60] and increased mean hemoglobin concentration in children[61]. Antenatal iron supplementation improved birth outcomes and reduced stunting[62].

Interventions that address malnutrition on the basis of one nutritional indicator may miss opportunities to address more nutritional problems. For example, in India low-income children who show signs of growth faltering are provided with extra food entitlements, but this strategy may miss other children vulnerable for anemia[63]. Conversely, Peru's strategies for provision of complementary food are hardly targeted at all[64]. Programs like Women Infants and Children (WIC) in the United States target low-income women and children with anemia; yet, our research shows that anemia may not be confined to low-income populations. While WIC uses anemia, underweight, and poor pregnancy outcomes as eligibility requirements[65], there may be a missed opportunity to address growth faltering in high risk families through the program. More research is needed to investigate the context-specific reasons these determinants differ between forms of child malnutrition and the co-occurrence of different forms of malnutrition.

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