Received: 10 May 2017 | Revised: 11 January 2018 | Accepted: 16 January 2018
DOI: 10.1111/mcn.12597

ORIGINAL ARTICLE

WILEY Maternal & Child Nutrition

The co-occurrence of anaemia and stunting in young children

Lucas Gosdin[1,2] | Reynaldo Martorell[1,2] | Rosario M. Bartolini[3] | Rukshan Mehta[2] | Sridhar Srikantiah[4] | Melissa F. Young[1,2]

[1] Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, Georgia, USA

[2] Doctoral Program in Nutrition and Health Sciences, Laney Graduate School, Emory University, Atlanta, Georgia, USA

[3] Instituto de Investigación Nutricional, Lima, Peru

[4] CARE India, Patna, India

Correspondence
Lucas Gosdin, MPH, Doctoral Program in Nutrition and Health Sciences, Laney Graduate School, Emory University, 1518 Clifton Road NE, CNR 5000-K, Atlanta, GA 30322, USA.
Email: lgosdin@emory.edu

Funding information
Bill & Melinda Gates Foundation; Regional Government of Lambayeque, Peru

Abstract

Anaemia and stunting are prevalent nutritional problems among children of low-income countries that have profound effects on development, morbidity, and mortality. Many use a single conceptual framework 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 affected individuals to a greater degree than by chance. In 2 populations of children—ages 6–18 months in Bihar, India, (n = 5,664) and 6–36 months in Lambayeque, Peru (n = 688)—we measured the frequency of the co-occurrence of anaemia and stunting. We compared this value with the value expected by chance, the product of the prevalence of anaemia and stunting, using a chi-square test. We also built logistic regression models for each condition. The frequency of co-occurrence in the Indian population was 21.5%, and in the Peruvian population, it was 30.4%, which are similar to frequencies expected by chance, 21.3% (p = .97) and 31.5% (p = .85). In Peru, anaemia was associated with age and consumption of treated water. Stunting was associated with age, sex, dietary diversity, hand washing, language spoken, and wealth. In India, anaemia was associated with age, sex, caste, dietary diversity, and household hunger. Stunting was associated with age, sex, caste, wealth, and maternal illiteracy. Despite some basic shared factors, anaemia and stunting are more independent than commonly assumed. Interventions that target children based on 1 condition may miss children with the other form of malnutrition.

KEYWORDS

anaemia, co-occurrence, infant nutrition, stunting

1 | INTRODUCTION

Affecting 273.2 million children ages 6–59 months worldwide and as many as 6 in 10 children in low- and middle-income countries (LMICs), anaemia is a widespread problem with consequences that extend beyond low haemoglobin concentration (World Health Organization, 2011a). Anaemia in children 6–59 months of age at sea level is defined by a blood haemoglobin concentration lower than 11 g/dL (WHO, 2001). There are many forms of anaemia; however, they can be grouped into two broad categories: nutritional anaemia and anaemia caused by disease or disorder (Balarajan, Ramakrishnan, Ozaltin, Shankar, & Subramanian, 2011). Nutritional anaemia can have a variety of causes including deficiencies of iron, Vitamin B12, and folate, whereas anaemia caused by disease or disorder can be chronic and hereditary or an acute response to a disease state (WHO, 2016). Iron deficiency anaemia (IDA) is thought to be the most common form of anaemia, although the exact proportion attributable to IDA is unclear and can vary widely from <1% to 75% depending on region and country (Petry et al., 2016; Stevens et al., 2013; WHO, 2011a). IDA is associated with negative impacts on brain function, metabolism, and immune function in children (Bryan et al., 2004; Hassan et al., 2016; Oexle, Gnaiger, & Weiss, 1999). Effects also include reduced mental capacity, delayed motor development, poor educational attainment, and reduced economic productivity (Balarajan et al., 2011; Haas & Brownlie, 2001). In fact, IDA is responsible for an estimated loss of over 51 million disability-adjusted life years (Institute for Health Metrics and Evaluation, 2015), and approximately US$3.82 per capita in economic losses are attributed to the decrease in physical and cognitive productivity caused by anaemia (Horton & Ross, 2007). 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 (Rao & Georgieff, 2007). This time between ages 1 and 2 years

presents the highest risk of anaemia, with risk declining subsequently; but in girls, it increases when reaching menarche (Alvarez-Uria, Naik, Midde, Yalla, & Pakam, 2014). Evidence supports supplementation, fortification, and treatment of anaemia-related diseases (World Bank, 2006). Despite efforts to address it, the prevalence of anaemia remains high in India and in Peru (Aguilar, 2016; WHO, 2011a). In Bihar, India, 63.5% of children ages 6–59 months have anaemia (Ministry of Health and Family Welfare—India, 2016). In Lambayeque, Peru the prevalence of anaemia in children 6–59 months is 26.9% (Aguilar, 2016).

Stunting, an indicator of chronic malnutrition, affects 159 million children under 5 globally, and LMICs, bearing a disproportionate burden of the condition, account for over 90% of the world's stunted children (United Nations Children's Fund, 2015). 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 healthy reference population of the same age and sex (WHO Multicentre Growth Reference Study Group, 2006). Stunting is associated with increased child morbidity, and mortality, reduced cognition, and decreased educational attainment (Adair et al., 2013; Black et al., 2013; Crookston et al., 2011; Hoddinott et al., 2013; Prendergast & Humphrey, 2014). The World Bank estimated that stunting reduces a person's lifetime earnings by 10% (World Bank, 2006). 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 (Shekar, Kaktietak, Eberwein, & Walters, 2016). However, there is strong evidence that the strongest risk factors for stunting are fetal growth restriction, preterm birth, and environmental exposures (i.e., unimproved sanitation; Danaei et al., 2016). Stunting develops during the first 1,000 days of life, and its effects are most likely irreversible after this period. Like most LMICs, India continues to bear a high burden of stunting in states like Bihar where the prevalence of stunting among children 6–59 months is 48.3% (Ministry of Health and Family Welfare—India, 2016). In contrast, Peru has made significant reductions in stunting over the past 20 years, attributable to antipoverty policies that affect social determinants (Huicho et al., 2017). Participation in the conditional cash transfer program (Programa JUNTOS), in particular, has been associated with better linear growth (Andersen et al., 2015). The prevalence of stunting among children 6–59 months in Peru is 9.3% and in the region of Lambayeque, 11.8% (Aguilar, 2016).

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 (UNICEF, 1990). The framework depicts shared causes at the population, household, and individual level for all types of malnutrition. The conceptual framework for anaemia developed by the World Bank Group and other frameworks for malnutrition are built upon these same causes (Shekar et al., 2016). If anaemia and growth faltering share basic causes, then an efficient use of resources would target the shared causes to eliminate various forms of malnutrition simultaneously. Under the shared-causes framework, interventions could potentially identify participants using one indicator of malnutrition rather than measuring children for various forms of malnutrition, and common interventions could be used to address them.

Key messages

- Although anaemia and stunting share some basic determinants, they do not co-occur in young children at a frequency greater than would be expected by chance.
- Interventions that target children based on anaemia will miss the opportunity to address stunting and vice versa.
- Stunting, in these populations, may be best reduced through targeting specific sociodemographics, whereas efforts to reduce anaemia may need to be more wide reaching.

Country-level analyses show that LMICs share a higher burden of undernutrition, including anaemia and stunting, than high-income countries (UNICEF–WHO–World Bank Group, 2015). This clustering of anaemia and stunting at the country level is consistent with clusters of need and unequal distribution of resources (World Bank, 2015a, b). Clustering of the conditions also occurs regionally (Ministry of Health and Family Welfare—India, 2006; Peru: Demographic and Family Health Survey, 2014). Clustering of undernutrition and overweight/obesity has led to the adoption of the term *double burden* or *dual burden* to signify the co-occurrence of two or more nutritional problems (WHO, 2017). 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 (Morgenstern, 1982). In Latin America, an increasing prevalence of overweight and obese adults and a high prevalence of child undernutrition led to a flurry of research into this dual burden at the national, community, and household level (Conde & Monteiro, 2014; Freire, Silva-Jaramillo, Ramirez-Luzuriaga, Belmont, & Waters, 2014; Kroker-Lobos, Pedroza-Tobias, Pedraza, & Rivera, 2014; Sarmiento et al., 2014). This research found that the dual burden of malnourished children with overweight or obese mothers did not co-occur at a frequency above what was expected by chance (Rivera, Pedraza, Martorell, & Gil, 2014). Further research found that the dual burden of child stunting and maternal overweight/obesity was a “statistical artefact” (Dieffenbach & Stein, 2012).

Although it is certain that some populations bear a higher burden of stunting and anaemia, it is unclear that they co-occur at a greater frequency than would be expected by chance among individuals. Few studies, mostly in Latin America, have examined the co-occurrence of anaemia and stunting (Palafox et al., 2003), and even fewer have compared the observed values with what is expected by chance (Albalak et al., 2000; Castejon et al., 2004). Results of these studies concluded that the frequency of co-occurring anaemia and stunting was not meaningfully greater than what one would expect by chance and concluded that the two conditions should be treated as independent (Albalak et al., 2000; Castejon et al., 2004). No currently available studies have combined

analysis of the co-occurrence of the two conditions with context-specific models of the underlying determinants of anaemia and stunting in young children.

The key question addressed in this analysis is whether anaemia and stunting co-occur beyond what is expected by chance, which would imply shared underlying determinants. This study has two specific aims: (a) to determine whether the co-occurrence of anaemia and stunting occurs more frequently than would be expected by chance and (b) to compare and contrast the key determinants of anaemia and stunting in Indian and Peruvian populations. 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 688 young children (6–36 months) in Lambayeque, Peru.

2 | METHODS

2.1 | Sample

We used data from two cross-sectional studies. Both samples were randomly selected using a multistage cluster probability proportional to size design. Seventy health subcentres treated as clusters were selected randomly from a single district in Bihar, India, as part of a home fortification randomized effectiveness trial—clinical trial NCT02593136 (Larson et al., 2017; Young et al., 2017). A random subsample of 5,664 children were assessed for haemoglobin and anthropometry from a larger survey listing of children 6–18 months of age residing in randomly selected villages within the assigned health subcentre. 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; for this analysis, we are only including children 6–36 months.

Anaemia was defined as blood haemoglobin concentration <11 g/dL adjusted for elevation (WHO, 2011b) and stunting, as length- or height-for-age less than two standard deviations (<−2 SD) below the mean of the sex-specific WHO reference population (WHO Multicentre Growth Reference Study Group, 2006). Haemoglobin was measured in the household by a HemoCue® beta-haemoglobin test using a finger or heel prick (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. Length/height-for-age *z* scores were calculated using the WHO Anthro SAS® macro version 3.3.2. Enumerators administered household surveys of basic demographics, health, and nutrition. In India, 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. The following variables were used in creating the Indian wealth index: housing materials, cooking materials, water sources, light sources, sanitation facilities, and ownership of a variety of 22 household items, farm animals, vehicles, and land. The Peruvian wealth index included a similar but smaller list of variables: housing materials, cooking fuels, water sources, light sources, sanitation facilities, farm animals, cellular telephone ownership, and primary occupation of the head of household. Infant and young child feeding (IYCF) practices were defined in accordance with the WHO guidelines (WHO, UNICEF, IFPRI, UC Davis,, & USAID, 2008). The following IYCF indicators were available for both sites: proportion currently breastfeeding, minimum dietary diversity (≥4 different food groups), and proportion breastfeeding for at least 6 months. Minimum dietary diversity was assessed differently for the Peruvian children: consuming at least four food groups at least once over the previous 7 days on a food frequency questionnaire rather that the 24-hour dietary diversity scale used in the Indian study; however, the food groups used were identical in both instances. Among the Indian children, we measured timely introduction of complementary foods (between 6 and 7 months of age), 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), and age-appropriate quantity of food (6–8 months: ½–1 katori, 9–11 months: ≥1 katori, and 12 months or older: >1 katori). Household hunger was assessed in India using the Household Hunger Scale and dichotomized into 0 and ≥1 (Ballard, Coates, Swindale, & Deitchler, 2011), whereas the Household Food Insecurity Access Scale was used in Peru and dichotomized into ≤3 and >3 (Coates, Swindale, & Bilinsky, 2007). There was not a true measure of parity in the Peruvian population because the number of births was recorded for only the previous 3 years. This was used as 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. Although other backward caste (OBC) was the largest social stratum in the sample, we avoided using it as the reference group for analysis because it is likely the most heterogeneous. We opted to use scheduled caste as the reference group due to the homogeneity and standing as the lowest caste in this context (Pankaj & Mishra, 2008). We also measured maternal-report of child diarrhoea, hospitalization, fever, and pneumonia in the previous 2 weeks; hand washing; and consumption of treated water.

2.2 | Analytic strategy

Contingency tables were generated for each site to determine the observed frequency of co-occurrence of anaemia and stunting, defined as having both conditions at the time of measurement. The product of the prevalence of anaemia and stunting was 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 α level was set at .05. Hypothesizing that the relationships between anaemia/stunting and age might affect the joint relationship, we stratified this analysis by age.

For predictive modelling, we first examined the bivariate relationships between household and individual factors available from the surveys and anaemia. We repeated the process for stunting. We built multiple logistic regression models for anaemia and stunting that included all variables that had a significant bivariate association with the corresponding independent variable, potential confounders shown in Tables 1 and 2, and specified interaction terms. We used variance

TABLE 1 Household characteristics

Demographics	India (n = 5,678)	Peru (n = 688)
Age, months	11.4 ± 3.4	18.5 ± 8.3
6–12	59.3	30.8
13–18	40.8	21.4
19–36	–	47.8
Female	49.0	47.4
Wealth tertile		
Highest	32.8	34.3
Middle	33.6	34.3
Lowest	33.6	31.4
Caste		
Scheduled caste	22.5	–
Scheduled tribe	9.1	–
Other backward caste	54.5	–
Other caste/outside system	13.9	–
Quechua speaking	–	8.4
Hindu	77.8	–
Maternal age, years	25.1 ± 4.7	29.4 ± 8.6
Maternal illiteracy	57.1	11.8
Maternal youth at marriage	60.3	–
Parity[a]	2.7 ± 1.6	1.1 ± 0.3
Household hunger[b]	6.6	27.2
Enrolment in social programs		
Conditional cash transfer (JUNTOS)	–	7.9
School feeding (Qaliwarma)	–	24.0
Daycare (Cuna Más)	–	1.6
Supplementary food (Vaso de Leche)	–	61.2

Note. Values are means ± SD or %.

[a]Parity in the Peruvian sample is a measure of children born to the mother only during the previous 3 years.

[b]Household Hunger Scale used for Indian children; Household Food Insecurity Access Scale for Peruvian.

inflation factor, variance decomposition proportions, and conditional indices to test for multicollinearity among our independent variables. We tested for potential interaction between the following variables among the Peruvian children: age and breastfeeding, age and minimum dietary diversity, sex and minimum dietary diversity, and conditional cash transfer and wealth index. We tested for interaction between the following variables among the Indian children: age and breastfeeding, age and minimum dietary diversity score, caste and food security, and age and appropriate quantity of food. We conducted a likelihood ratio test of the interaction terms. The model was reduced to include only associated and confounding variables. Confounding was assessed by two criteria: plausibility after drawing directed acyclic graphs of the confounding relationships 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 used SAS® survey procedures to properly adjust the standard errors to account for the multilevel cluster sampling strategy. For sensitivity analysis, we repeated these analyses for haemoglobin <10 g/dL, and in a subsequent analysis, we restricted the Peruvian dataset to those aged 6–18 months to observe the model's performance (data not shown). Alpha level for regression analysis was .05. The Internal Review Boards of the Instituto de Investigación Nutricional and Emory University approved the original studies and exempted this secondary data analysis from further review.

3 | RESULTS

Demographic information for each population is provided in Table 1. There were no differences in demographics by age group in either population. The prevalence of anaemia in the Indian children was 68.8% with a mean haemoglobin concentration of 10.2 g/dL. The prevalence of stunting was 31% with a mean length-for-age z score of −1.4 (Table 2). The prevalence of anaemia in the Peruvian children was 71.3% with a mean haemoglobin concentration of 10.2 g/dL. The prevalence of stunting was 44.2% with a mean height-for-age z score of −1.8 (Table 2).

The observed frequency of co-occurrence was 21.5% among the Indian children and 30.4% among the Peruvian children. The expected frequency of co-occurrence by chance was 21.3% in the sample of Indian children and 31.5% in the sample of Peruvian children. There was no statistically significant difference between the observed and expected frequency of co-occurrence nor did these comparisons vary by age (Table 3).

Among the Indian children, statistically significant bivariate relationships existed between anaemia and the following variables: sex, caste, dietary diversity, and household hunger. In bivariate models, stunting was associated with child age, sex, maternal youth at marriage, maternal illiteracy, parity, caste, wealth tertile, age-appropriate quantity of food consumed, and prevalence of diarrhoea, fever, and symptoms of pneumonia. Among the Peruvian children, statistically significant bivariate relationships existed between anaemia and the variables child's age, wealth tertile, and consumption of treated water. Stunting in the Peruvian children was associated with child's age, child sex, parity, wealth tertile, language spoken, dietary diversity, consumption of treated water, and hand washing with soap (Table 4). Other variables not associated with either outcome included religion, mother's age, meal frequency, currently breastfeeding, breastfeeding for at least 6 months, timely introduction of complementary foods, hospitalization in the previous 2 weeks, deworming in the previous 4 months, and having an anaemia control visit in the previous 4 months.

In the multivariate logistic regressions models, none of the interaction terms was statistically significant—$p > .05$ for the likelihood ratio test—and were subsequently removed from the model. The breastfeeding variables were determined to be collinear with child's age and removed from the model. In Peru, the parity variable measuring births only during the previous 3 years was also collinear with age and was not included in final model. Information on enrolment in social protection programs was only available for the Peruvian children (Table 1). These factors were associated with higher prevalence of anaemia and stunting; however, this is due to the targeting of these programs to children at high risk for under nutrition. These programs were not mediators of the relationship between socioeconomic factors and undernutrition nor did they confound the other variables in the multivariate model.

TABLE 2 Child feeding practices, health, hygiene, and nutritional status by age group

	India			Peru			
Child feeding practices	**6–12 months (*n* = 3,364)**	**13–18 months (*n* = 2,314)**	**Total (*n* = 5,678)**	**6–12 months (*n* = 212)**	**13–18 months (*n* = 147)**	**19–36 months (*n* = 329)**	**Total (*n* = 688)**
Minimum dietary diversity score[a]	25.4	36.2	29.8	64.6	74.8	78.7	73.6
Age-appropriate quantity of food	4.9	3.9	4.5	–	–	–	–
Timely initiation of food	39.5	41.4	40.3	–	–	–	–
Minimum meal frequency	65.1	76.2	69.8	–	–	–	–
Current breastfeeding	96.9	90.8	94.4	96.2	86.2	44.7	69.3
Breastfeeding for ≥6 months	99.5	99.3	99.4	97.6	98.0	95.4	96.7
Health							
Diarrhoea in previous 2 weeks	12.9	12.2	12.6	36.7	33.6	29.4	32.5
Hospitalization in previous 2 weeks	0.7	0.9	0.8	–	–	–	–
Fever in previous 2 weeks	52.8	47.3	50.5	47.2	42.9	39.8	42.7
Pneumonia symptoms in previous 2 weeks	34.1	33.8	34.0	53.3	54.4	46.5	50.3
Deworming, previous 4 months	–	–	–	2.4	7.0	11.7	7.8
Anaemia control visit, previous 4 months	–	–	–	17.2	8.9	9.7	11.9
Water and hygiene							
Caregiver's hands washed with soap	36.2	43.3	39.1	83.0	79.6	85.4	83.4
Household consumes treated water	–	–	–	70.8	70.1	74.5	72.4
Anthropometry and haemoglobin							
Haemoglobin (Hb, g/dL)	10.3 ± 1.5	10.2 ± 1.4	10.2 ± 1.5	9.8 ± 1.2	10.0 ± 1.3	10.6 ± 1.2	10.2 ± 1.3
Anaemia (Hb < 11 g/dL)	68.2	69.5	68.8	87.3	76.9	58.7	71.3
Height-for-age *z* score	−1.2 ± 1.2	−1.8 ± 1.2	−1.4 ± 1.2	−1.3 ± 1.2	−1.9 ± 1.1	−2.1 ± 1.1	−1.8 ± 1.2
Stunting (≤−2 SD ht/age)	23.6	41.6	31	28.3	43.5	54.7	44.2

Note. Values are means ± SD or %.

[a]Minimum dietary diversity and household hunger used different measurement instruments in each population.

TABLE 3 Comparison of the observed co-occurrence of anaemia and stunting with the expected chance co-occurrence

Population	Observed co-occurrence (%)	Expected co-occurrence (%)	χ^2	*p*
India, months	21.5	21.3	0.001	.97
6–12	14.9	14.9	0.000	>.99
13–18	27.9	27.8	0.036	.85
Peru, months	30.4	31.5	0.038	.84
6–12	24.5	24.7	0.002	.69
13–18	34.7	33.5	0.000	.98
19–36	32.2	32.1	0.000	.99

Factors protective against anaemia in a multiple logistic regression model of the Indian children included being female, being in OBC or other caste relative to scheduled caste, and attainment of minimum diet diversity. Household hunger was associated with increased odds of anaemia. Factors protective against stunting in a multiple logistic regression model of the Indian children included being female and belonging to a scheduled tribe or OBC relative to scheduled caste. Factors associated with increased odds of stunting included increasing age of the child, maternal youth at marriage, maternal illiteracy, and being in lowest or middle wealth tertile relative to the highest (Table 5). In the multivariate models, we also controlled for potential confounders that had significant bivariate relationships with the respective outcomes. None of these variables confounded the exposure–disease relationships in the models.

Although constrained by the much smaller sample size, the multivariate models of anaemia and stunting among the Peruvian children have some similarities. The adjusted model shows that anaemia is inversely associated with age whereas stunting is positively associated with age. Consumption of treated water was protective against anaemia. Being female, consumption of a minimally diverse diet, and hand washing with soap were associated with decreased odds of stunting, whereas lower wealth tertile and speaking Quechua and not Spanish were associated with increased odds of stunting (Table 5).

4 | DISCUSSION

As in previous studies (Albalak et al., 2000; Castejon et al., 2004), there was no meaningful difference in the co-occurrence of anaemia and stunting compared with what was expected by chance suggesting that anaemia and stunting are more independent than commonly assumed. The UNICEF conceptual framework for the causes of malnutrition (UNICEF, 1990) 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. This analysis suggests that co-occurrence of the conditions may be the result of chance rather than shared determinants. To investigate this further, we examined available factors that could be categorized into basic, underlying, and immediate

TABLE 4 Bivariate association between nutritional deficiencies and related variables

Variable	India, OR (95% CI) Anaemia	India, OR (95% CI) Stunting	Peru, OR (95% CI) Anaemia	Peru, OR (95% CI) Stunting
Child's age in months	1.02 (0.99, 1.04)	**1.15 (1.13, 1.17)**	**0.93 (0.91, 0.95)**	**1.05 (1.03, 1.08)**
Female child	**0.78 (0.70, 0.87)**	**0.78 (0.69, 0.88)**	1.04 (0.76, 1.42)	**0.74 (0.54, 1.02)**
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 (0.48, 1.36)	1.55 (1.00, 2.41)
Parity[a]	0.98 (0.95, 1.02)	**1.11 (1.07, 1.16)**	1.72 (0.85, 3.47)	0.65 (0.38, 1.11)
Scheduled caste	Ref	Ref	–	–
Scheduled tribe	1.16 (0.86, 1.57)	**0.54 (0.44, 0.67)**	–	–
Other backward caste	**0.67 (0.59, 0.77)**	**0.54 (0.43, 0.68)**	–	–
Other caste	**0.75 (0.62, 0.91)**	**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)**	1.15 (0.75, 1.74)	**2.45 (1.58, 3.80)**
Middle wealth tertile	1.03 (0.89, 1.18)	**1.78 (1.52, 2.08)**	**1.69 (1.10, 2.60)**	**1.76 (1.12, 2.75)**
Spanish speaking	–	–	Ref	Ref
Quechua speaking	–	–	1.24 (0.73, 2.10)	**2.78 (1.47, 5.26)**
Bilingual	–	–	1.65 (0.57, 4.77)	2.53 (0.97, 6.61)
Minimum dietary diversity[b]	**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[c]	**1.47 (1.13, 1.91)**	1.14 (0.91, 1.44)	1.23 (0.82, 1.84)	1.22 (0.81, 1.84)
Age appropriate quantity of food	1.06 (0.81–1.40)	**0.73 (0.56–0.96)**	–	–
Diarrhoea, previous 2 weeks	0.95 (0.78, 1.16)	**1.22 (1.01, 1.47)**	1.10 (0.78, 1.56)	0.98 (0.68, 1.41)
Fever, previous 2 weeks	1.10 (0.96, 1.26)	**1.17 (1.03, 1.34)**	1.36 (0.98, 1.90)	1.16 (0.84, 1.59)
Symptoms of pneumonia, previous 2 weeks	1.00 (0.84, 1.20)	**1.27 (1.03, 1.56)**	1.19 (0.86, 1.65)	1.00 (0.73, 1.35)
Consumption of treated water	–	–	**0.65 (0.44, 0.95)**	**0.63 (0.44, 0.91)**
Hand washing with soap	0.97 (0.87, 1.09)	**0.88 (0.78, 0.98)**	0.92 (0.57, 1.47)	**0.48 (0.31, 0.73)**

Note. Statistically significant results ($p < .05$) are bolded. CI = confidence interval; OR = odds ratio.

[a]Parity in the Peruvian sample is a measure of children born to the mother in the previous 3 years.

[b]Recall period for minimum dietary diversity was 24 hr for Indian children; 7 days for Peruvian children.

[c]Household Hunger Scale used for Indian children; Household Food Insecurity Access Scale for Peruvian.

causes of each condition as described by the UNICEF framework (UNICEF, 1990).

Basic factors available for analysis in both populations included household wealth and social standing. These socio-economic factors were associated with stunting in both countries, consistent with findings from longitudinal studies (Mal-Ed Network Investigators, 2017). Children in lower economic strata are less capable of mitigating the effects of the same exposures (Barros, Victora, Scherpbier, & Gwatkin, 2010). Caste was associated with anaemia in India. However, wealth was not associated with anaemia in India. One potential explanation may be the vegetarian diet consumed by Indian children across economic strata that tends to be low in bioavailable iron (Nair & Iyengar, 2009). Among the Indian children, only 15% of children in each wealth tertile consumed flesh foods in the previous 24 hr. In contrast, in Peru, consumption of flesh foods over the previous 7 days was not evenly distributed across wealth tertiles: 46% of the lowest, 60% of the middle, and 88% of the wealthiest tertile. However, further research on iron status is needed to understand the role of nutritional deficiencies in the aetiology of anaemia in both contexts. We also recorded religion in India and enrolment in social protections programs in Peru. Religion did not have a significant relationship with either condition. The Peruvian social protection programs would be biased predictors of stunting and anaemia because they target children who are at higher risk. They were not effect modifiers or mediators of the relationship between socio-economic status and anaemia or stunting so were not included in final models for this analysis.

Potential underlying determinants available in both populations included maternal age and education, household hunger, and caregiver hand washing behaviour. In India, maternal education was associated with stunting and household hunger was associated with anaemia. This is consistent with previous studies (Dorsey et al., 2017; Eicher-Miller, Mason, Weaver, McCabe, & Boushey, 2009). In Peru, caregivers' hand washing behaviour was associated with stunting, in line with evidence that sanitation and hygiene can help reduce the burden of stunting (Cumming & Cairncross, 2016). In India, we also recorded maternal youth at marriage and parity, and in Peru, we recorded deworming and anaemia control visits as well as household consumption of treated water. Of these variables, only consumption of treated water was associated with anaemia.

In both populations, we categorized several available factors as immediate determinants of child nutritional status including age, sex, dietary diversity, breastfeeding behaviours, and recent history of diarrhoea, fever, and symptoms of pneumonia. As expected, we observed increased stunting with age (Victora, de Onis, Hallal, Blossner, & Shrimpton, 2010). In the Peruvian population, we found that age was also significantly associated with anaemia. We were

TABLE 5 Multivariate regression model of underlying variables associated with anaemia and stunting

	India, aOR (95% CI)		Peru, aOR (95% CI)	
Variable	**Anaemia**	**Stunting**	**Anaemia**	**Stunting**
Child's age in months	1.02 (1.00, 1.04)	**1.16 (1.13, 1.19)**	**0.93 (0.90, 0.95)**	**1.07 (1.04, 1.09)**
Being a female child	**0.77 (0.69, 0.87)**	**0.72 (0.61, 0.86)**	1.05 (0.75, 1.47)	**0.62 (0.44, 0.87)**
Maternal youth at marriage	–	1.13 (0.91, 1.39)		
Maternal illiteracy	–	**1.43 (1.18, 1.72)**	–	–
Parity	–	1.04 (0.98, 1.10)	–	–
Scheduled caste	Ref	Ref	–	–
Scheduled tribe	1.19 (0.88, 1.61)	**0.49 (0.36, 0.68)**	–	–
Other backward caste	**0.68 (0.59, 0.78)**	**0.76 (0.59, 0.98)**	–	–
Other caste	**0.76 (0.62, 0.93)**	0.75 (0.53, 1.06)	–	–
Highest wealth tertile	–	Ref	Ref	Ref
Lowest wealth tertile	–	**1.72 (1.36, 2.17)**	0.87 (0.56, 1.37)	**2.08 (1.29, 3.33)**
Middle wealth tertile	–	**1.51 (1.20, 1.90)**	1.53 (0.98, 2.41)	**1.70 (1.05, 2.74)**
Spanish speaking	–	–	–	Ref
Quechua speaking	–	–	–	**2.31 (1.19, 4.47)**
Bilingual	–	–	–	2.35 (0.96, 5.78)
Minimum dietary diversity[a]	**0.87 (0.75, 1.00)**	–	–	**0.60 (0.39, 0.93)**
Household hunger	**1.47 (1.14, 1.91)**	–	–	–
Age appropriate quantity of food	–	0.89 (0.61, 1.29)	–	–
Diarrhoea, previous 2 weeks	–	1.22 (0.95, 1.57)	–	–
Fever, previous 2 weeks	–	0.92 (0.75, 1.13)	–	–
Symptoms of pneumonia, previous 2 weeks	–	1.18 (0.95, 1.46)	–	–
Consumption of treated water	–	–	**0.63 (0.42, 0.96)**	0.85 (0.57, 1.27)
Hand washing with soap	–	0.95 (0.78, 1.16)	–	**0.57 (0.36, 0.89)**

Note. Statistically significant results ($p < .05$) are bolded. aOR = adjusted odds ratio; CI = confidence interval.

[a]Recall period for minimum dietary diversity was 24 hr for Indian children; 7 days for Peruvian children.

concerned about issues of gender inequalities that disadvantage girls; however, we found that being female was negatively associated with anaemia and stunting in this age group, consistent with other literature (Alvarez-Uria et al., 2014; Foote et al., 2013; Sobrino, Gutierrez, Cunha, Davila, & Alarcon, 2014). The most common hypothesis for this difference in anaemia between sexes is the increased iron requirements in males due to rapid gains in muscle mass (Antunes, Santos, Carvalho, Gonçalves, & Costa-Pereira, 2012). Dietary diversity was associated with reduced stunting among the Peruvian children, but among the Indian children, it was associated with reduced anaemia. This could be a result of the differential recall periods for measuring dietary diversity. The Peruvian questionnaire was a better measure of usual intake rather than recent intake. Nonetheless, consumption of a diverse diet may be important for both growth and anemia prevention. Breastfeeding behaviours were collinear with age of the child and were not included in the models. Recent health issues were not significant predictors of undernutrition in either population. In India, we had more measures of child feeding practices including quantity of food, initiation of complementary foods, and meal frequency as well as recent history of hospitalization. These factors were not associated with either condition in multivariate models.

Although the two nutritional conditions shared some associated factors, other economic, health, and household characteristics were differentially associated with each outcome. We have shown that the co-occurrence of anaemia and stunting 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 both anaemia and stunting did not show evidence of a relationship between the two among individuals.

Differences in the duration of anaemia and stunting present a challenge for examining their co-occurrence. Anaemia was determined by haemoglobin values that can vary slightly from day to day (Belza, Ersboll, Henriksen, Thilsted, & Tetens, 2005). Conversely, stunting is based on linear growth and change is very gradual. To determine the sensitivity of our analysis to the variability of haemoglobin, we repeated our analyses using a lower cut-off for anaemia (<10 g/dL; data not shown). The implications were the same, and there were no differences between the observed and expected values of co-occurrence of anaemia and stunting among either population. The model of the determinants of anaemia showed similar relationships in India, whereas only age remained a statistically significant predictor in the Peruvian model.

As in all secondary data analyses, we were limited to the survey questions from each original study. Some of the measures such as caste and indigenous language were context specific, whereas others were not recorded. There are also limitations to some of the self-reported measures such as hand washing and consumption of treated water that may be subjects to response bias. Child age also varied in the two datasets. To address this, we conducted a sensitivity analysis

for Peru limited to children 6–18 months and a similar trend was noted but power was greatly reduced. Due to the lack of some important measures and a much smaller sample size over a larger geographical area (more clusters), there was a reduced precision in the models of the Peruvian children. Although combining the datasets for the regression modelling may have facilitated direct estimation of the differences between the countries, this was not feasible due to the differences in the measures and sampling strategies between the studies. Although not directly comparable, the models provide a comparison of the directionality of the association. We were also missing some key variables that have been important to stunting and anaemia in other studies including maternal nutrition, birth weight, gestational age at birth, and other environmental indicators (Balarajan et al., 2011; Danaei et al., 2016). 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 anaemia and stunting. A prospective cohort study through the first 1,000 days of life that includes the aforementioned variables and biomarkers would reduce these limitations.

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. Efficient efforts to reduce stunting may target lower economic strata, whereas interventions spanning socio-economic strata may be needed to address anaemia. Although there is no single solution to both problems, interventions may not be mutually exclusive. Income-generating activities, targeted supplementation, and equitable access to contraception may have a stronger impact on stunting, whereas staple food fortification and wide-reaching iron supplementation and IYCF education may better impact anaemia. Improvements in water, sanitation, and hygiene may improve both outcomes. Income-generating interventions can improve the underlying determinants of stunting (Haselow, Stormer, & Pries, 2016). Supplementation with zinc can significantly increase mean gain in height (Imdad & Bhutta, 2011), and public provision of complementary foods in food insecure settings can significantly reduce the odds of stunting in children (Bhutta et al., 2008). There is evidence that unwanted and mistimed pregnancies are associated with increased odds of the child being stunted (Rahman, 2015; Shapiro-Mendoza, Selwyn, Smith, & Sanderson, 2005). Mandated staple food fortification with iron significantly decreased anaemia (Martorell et al., 2015) and increased mean haemoglobin concentration in children (Das, Salam, Kumar, & Bhutta, 2013). Antenatal iron supplementation improved birth outcomes and reduced stunting (Pena-Rosas, De-Regil, Garcia-Casal, & Dowswell, 2015).

Interventions that address malnutrition on the basis of one nutritional indicator may miss opportunities to address other 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 anaemia (The National Food Security Bill, Republic of India, 2013). Conversely, Peru's strategies for provision of complementary food are hardly targeted at all (Valdivia, 2005). Programs such as Women Infants and Children in the United States target low-income women and children with anaemia; yet research shows that anaemia may not be confined to low-income populations. More research is needed into the context-specific reasons these determinants differ between forms of child malnutrition and the co-occurrence of different forms of malnutrition.

5 | CONCLUSIONS

Our research adds to the evidence that anaemia and stunting should be treated as independent conditions. It must not be assumed that interventions that address an underlying determinant of anaemia will have a complementary reduction in stunting. Targeting one condition would not identify or address the other condition simultaneously in these populations. We recommend a multistrategy approach to target the determinants of both anaemia and stunting to have the greatest impact. Future research should examine the co-occurrence of additional forms of malnutrition.

ACKNOWLEDGMENTS

We acknowledge CARE India and the Instituto de Investigación Nutricional for providing the data for this analysis.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

CONTRIBUTIONS

LG, MY, and R. Martorell conceived the study design and devised the analysis plan. LG conducted the analyses, interpreted the results, and wrote the first draft of the manuscript. MY and R. Martorell contributed to the interpretation of results and the writing of the manuscript. RB led the data collection in Peru, and R. Mehta and SS led data collection in India. RB, R. Mehta, and SS contributed to the interpretation of the results. All authors read and approved the final version of the manuscript.

ORCID

Lucas Gosdin http://orcid.org/0000-0002-5896-3403
Melissa F. Young http://orcid.org/0000-0002-2768-1673

REFERENCES

Adair, L. S., Fall, C. H., Osmond, C., Stein, A. D., Martorell, R., Ramirez-Zea, M., … COHORTS group (2013). Associations of linear growth and relative weight gain during early life with adult health and human capital in countries of low and middle income: Findings from five birth cohort studies. *Lancet*, *382*(9891), 525–534. https://doi.org/10.1016/S0140-6736(13)60103-8

Aguilar, A. S. (2016). *Peru: Demographic and Family Health Survey*. Lima, Peru: National Institute of Statistics and Informatics.

Albalak, R., Ramakrishnan, U., Stein, A. D., Van der Haar, F., Haber, M. J., Schroeder, D., & Martorell, R. (2000). Co-occurrence of nutrition problems in Honduran children. *The Journal of Nutrition*, *130*(9), 2271–2273.

Alvarez-Uria, G., Naik, P. K., Midde, M., Yalla, P. S., & Pakam, R. (2014). Prevalence and severity of anaemia stratified by age and gender in rural India. *Anemia*, *2014*, 176182. https://doi.org/10.1155/2014/176182

Andersen, C. T., Reynolds, S. A., Behrman, J. R., Crookston, B. T., Dearden, K. A., Escobal, J., … Fernald, L. C. (2015). Participation in the *Juntos*

conditional cash transfer program in Peru is associated with changes in child anthropometric status but not language development or school achievement. *The Journal of Nutrition*, *145*(10), 2396–2405. https://doi.org/10.3945/jn.115.213546

Antunes, H., Santos, C., Carvalho, S., Gonçalves, S., & Costa-Pereira, A. (2012). Male gender is an important clinical risk factor for iron deficiency in healthy infants. *e-SPEN Journal*, *7*(6), e219–e222. https://doi.org/10.1016/j.clnme.2012.09.001

Balarajan, Y., Ramakrishnan, U., Ozaltin, E., Shankar, A. H., & Subramanian, S. V. (2011). Anaemia in low-income and middle-income countries. *Lancet*, *378*(9809), 2123–2135. https://doi.org/10.1016/S0140-6736(10)62304-5

Ballard, T., Coates, J., Swindale, A., & Deitchler, M. (2011). *Household Hunger Scale: Indicator definition and measurement guide*. Washington, D.C.: Food and Nutrition Technical Assistance II Project, FHI 360.

Barros, F. C., Victora, C. G., Scherpbier, R., & Gwatkin, D. (2010). Socioeconomic inequities in the health and nutrition of children in low/middle income countries. *Revista de Saúde Pública*, *44*(1), 1–16.

Belza, A., Ersboll, A. K., Henriksen, M., Thilsted, S. H., & Tetens, I. (2005). Day-to-day variation in iron-status measures in young iron-deplete women. *The British Journal of Nutrition*, *94*(4), 551–556.

Bhutta, Z. A., Ahmed, T., Black, R. E., Cousens, S., Dewey, K., Giugliani, E., … Child Undernutrition Study Group (2008). What works? Interventions for maternal and child undernutrition and survival. *Lancet*, *371*(9610), 417–440. https://doi.org/10.1016/S0140-6736(07)61693-6

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., de Onis, M., … Child Nutrition Study Group (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet*, *382*(9890), 427–451. https://doi.org/10.1016/S0140-6736(13)60937-X

Bryan, J., Osendarp, S., Hughes, D., Calvaresi, E., Baghurst, K., & van Klinken, J. W. (2004). Nutrients for cognitive development in school-aged children. *Nutrition Reviews*, *62*(8), 295–306.

Castejon, H. V., Ortega, P., Amaya, D., Gomez, G., Leal, J., & Castejon, O. J. (2004). Co-existence of anemia, vitamin A deficiency and growth retardation among children 24-84 months old in Maracaibo, Venezuela. *Nutritional Neuroscience*, *7*(2), 113–119. https://doi.org/10.1080/10284150410001704534

Coates, J., Swindale, A., & Bilinsky, P. (2007). *Household Food Insecurity Access Scale (HFIAS) for measurement of household food access: Indicator guide (v. 3)*. Washington, D.C.: Food and Nutrition Technical Assistance II Project, FHI 360.

Conde, W. L., & Monteiro, C. A. (2014). Nutrition transition and double burden of undernutrition and excess of weight in Brazil. *The American Journal of Clinical Nutrition*, *100*(6), 1617S–1622S. https://doi.org/10.3945/ajcn.114.084764

Crookston, B. T., Dearden, K. A., Alder, S. C., Porucznik, C. A., Stanford, J. B., Merrill, R. M., … Penny, M. E. (2011). Impact of early and concurrent stunting on cognition. *Maternal & Child Nutrition*, *7*(4), 397–409. https://doi.org/10.1111/j.1740-8709.2010.00255.x

Cumming, O., & Cairncross, S. (2016). Can water, sanitation and hygiene help eliminate stunting? Current evidence and policy implications. *Maternal & Child Nutrition*, *12*(Suppl 1), 91–105. https://doi.org/10.1111/mcn.12258

Danaei, G., Andrews, K. G., Sudfeld, C. R., Fink, G., McCoy, D. C., Peet, E., … Fawzi, W. W. (2016). Risk factors for childhood stunting in 137 developing countries: A comparative risk assessment analysis at global, regional, and country levels. *PLoS Medicine*, *13*(11), e1002164. https://doi.org/10.1371/journal.pmed.1002164

Das, J. K., Salam, R. A., Kumar, R., & Bhutta, Z. A. (2013). Micronutrient fortification of food and its impact on woman and child health: A systematic review. *Systematic Reviews*, *2*, 67. https://doi.org/10.1186/2046-4053-2-67

Dieffenbach, S., & Stein, A. D. (2012). Stunted child/overweight mother pairs represent a statistical artifact, not a distinct entity. *The Journal of Nutrition*, *142*(4), 771–773. https://doi.org/10.3945/jn.111.153387

Dorsey, J. L., Manohar, S., Neupane, S., Shrestha, B., Klemm, R. D., & West, K. P. Jr. (2017). Individual, household, and community level risk factors of stunting in children younger than 5 years: Findings from a national surveillance system in Nepal. *Maternal & Child Nutrition*. https://doi.org/10.1111/mcn.12434

Eicher-Miller, H. A., Mason, A. C., Weaver, C. M., McCabe, G. P., & Boushey, C. J. (2009). Food insecurity is associated with iron deficiency anemia in US adolescents. *The American Journal of Clinical Nutrition*, *90*(5), 1358–1371. https://doi.org/10.3945/ajcn.2009.27886

Foote, E. M., Sullivan, K. M., Ruth, L. J., Oremo, J., Sadumah, I., Williams, T. N., & Suchdev, P. S. (2013). Determinants of anemia among preschool children in rural, western Kenya. *The American Journal of Tropical Medicine and Hygiene*, *88*(4), 757–764. https://doi.org/10.4269/ajtmh.12-0560

Freire, W. B., Silva-Jaramillo, K. M., Ramirez-Luzuriaga, M. J., Belmont, P., & Waters, W. F. (2014). The double burden of undernutrition and excess body weight in Ecuador. *The American Journal of Clinical Nutrition*, *100*(6), 1636S–1643S. https://doi.org/10.3945/ajcn.114.083766

Haas, J. D., & Brownlie, T.t. (2001). Iron deficiency and reduced work capacity: A critical review of the research to determine a causal relationship. *The Journal of Nutrition*, *131*(2S-2), 676S–688S. discussion 688S–690S

Haselow, N. J., Stormer, A., & Pries, A. (2016). Evidence-based evolution of an integrated nutrition-focused agriculture approach to address the underlying determinants of stunting. *Maternal & Child Nutrition*, *12*(Suppl 1), 155–168. https://doi.org/10.1111/mcn.12260

Hassan, T. H., Badr, M. A., Karam, N. A., Zkaria, M., El Saadany, H. F., Abdel Rahman, D. M., … Selim, A. M. (2016). Impact of iron deficiency anemia on the function of the immune system in children. *Medicine (Baltimore)*, *95*(47), e5395. https://doi.org/10.1097/MD.0000000000005395

Hoddinott, J., Behrman, J. R., Maluccio, J. A., Melgar, P., Quisumbing, A. R., Ramirez-Zea, M., … Martorell, R. (2013). Adult consequences of growth failure in early childhood. *The American Journal of Clinical Nutrition*, *98*(5), 1170–1178. https://doi.org/10.3945/ajcn.113.064584

Horton, S., & Ross, J. (2007). Corrigendum to: "The economics of iron deficiency" [Food Policy 28 (2003) 51–75]. *Food Policy*, *32*(1), 141–143.

Huicho, L., Huayanay-Espinoza, C. A., Herrera-Perez, E., Segura, E. R., Nino de Guzman, J., Rivera-Ch, M., & Barros, A. J. (2017). Factors behind the success story of under-five stunting in Peru: A district ecological multilevel analysis. *BMC Pediatrics*, *17*(1), 29. https://doi.org/10.1186/s12887-017-0790-3

Imdad, A., & Bhutta, Z. A. (2011). Effect of preventive zinc supplementation on linear growth in children under 5 years of age in developing countries: A meta-analysis of studies for input to the lives saved tool. *BMC Public Health*, *11*(Suppl 3), S22. https://doi.org/10.1186/1471-2458-11-S3-S22

Institute for Health Metrics and Evaluation. (2015). Global health data exchange Retrieved from http://ghdx.healthdata.org/gbd-results-tool

Kroker-Lobos, M. F., Pedroza-Tobias, A., Pedraza, L. S., & Rivera, J. A. (2014). The double burden of undernutrition and excess body weight in Mexico. *The American Journal of Clinical Nutrition*, *100*(6), 1652S–1658S. https://doi.org/10.3945/ajcn.114.083832

Larson, L., Young, M., Bauer, P., Mehta, R., Webb Girard, A., Ramakrishnan, U., … Martorell, R. (2017). Home fortification with multiple micronutrient powders improves infant and young child development in Bihar, India. *The FASEB Journal*, *31*(1 Supplement), 436–466.

Mal-Ed Network Investigators (2017). Childhood stunting in relation to the pre- and postnatal environment during the first 2 years of life: The MAL-ED longitudinal birth cohort study. *PLoS Medicine*, *14*(10), e1002408. https://doi.org/10.1371/journal.pmed.1002408

Martorell, R., Ascencio, M., Tacsan, L., Alfaro, T., Young, M. F., Addo, O. Y., … Flores-Ayala, R. (2015). Effectiveness evaluation of the food fortification program of Costa Rica: Impact on anemia prevalence and hemoglobin concentrations in women and children. *The American Journal of Clinical Nutrition*, *101*(1), 210–217. https://doi.org/10.3945/ajcn.114.097709

Ministry of Health and Family Welfare—India (2006). *National Family and Health Survey 2005–06*. Mumbai: International Institute for Population Science.

Ministry of Health and Family Welfare—India (2016). *National Family and Health Survey 2015–16: State fact sheet Bihar*. Mumbai: International Institute for Population Science.

Morgenstern, H. (1982). Uses of ecologic analysis in epidemiologic research. *American Journal of Public Health*, *72*(12), 1336–1344.

Nair, K. M., & Iyengar, V. (2009). Iron content, bioavailability & factors affecting iron status of Indians. *The Indian Journal of Medical Research*, *130*(5), 634–645.

Oexle, H., Gnaiger, E., & Weiss, G. (1999). Iron-dependent changes in cellular energy metabolism: Influence on citric acid cycle and oxidative phosphorylation. *Biochimica et Biophysica Acta*, *1413*(3), 99–107.

Palafox, N. A., Gamble, M. V., Dancheck, B., Ricks, M. O., Briand, K., & Semba, R. D. (2003). Vitamin A deficiency, iron deficiency, and anemia among preschool children in the Republic of the Marshall Islands. *Nutrition*, *19*(5), 405–408.

Pankaj, A. K., & Mishra, N. K. (2008). *A baseline survey of minority concentration districts of India: Paschim Champaran*. Ministry of Miniority Affairs Government of India and Indian Council of Social Science Research: Bihar.

Pena-Rosas, J. P., De-Regil, L. M., Garcia-Casal, M. N., & Dowswell, T. (2015). Daily oral iron supplementation during pregnancy. *Cochrane Database of Systematic Reviews*, *7*, CD004736. https://doi.org/10.1002/14651858.CD004736.pub5

Peru: Demographic and Family Health Survey. (2014). Retrieved from Lima, Peru:

Petry, N., Olofin, I., Hurrell, R. F., Boy, E., Wirth, J. P., Moursi, M., … Rohner, F. (2016). The proportion of anemia associated with iron deficiency in low, medium, and high human development index countries: A systematic analysis of national surveys. *Nutrients*, *8*(11). https://doi.org/10.3390/nu8110693

Prendergast, A. J., & Humphrey, J. H. (2014). The stunting syndrome in developing countries. *Paediatrics and International Child Health*, *34*(4), 250–265. https://doi.org/10.1179/2046905514Y.0000000158

Rahman, M. M. (2015). Is unwanted birth associated with child malnutrition in Bangladesh? *International Perspectives on Sexual and Reproductive Health*, *41*(2), 80–88. https://doi.org/10.1363/4108015

Rao, R., & Georgieff, M. K. (2007). Iron in fetal and neonatal nutrition. *Seminars in Fetal & Neonatal Medicine*, *12*(1), 54–63. https://doi.org/10.1016/j.siny.2006.10.007

Rivera, J. A., Pedraza, L. S., Martorell, R., & Gil, A. (2014). Introduction to the double burden of undernutrition and excess weight in Latin America. *The American Journal of Clinical Nutrition*, *100*(6), 1613S–1616S. https://doi.org/10.3945/ajcn.114.084806

Sarmiento, O. L., Parra, D. C., Gonzalez, S. A., Gonzalez-Casanova, I., Forero, A. Y., & Garcia, J. (2014). The dual burden of malnutrition in Colombia. *The American Journal of Clinical Nutrition*, *100*(6), 1628S–1635S. https://doi.org/10.3945/ajcn.114.083816

Shapiro-Mendoza, C., Selwyn, B. J., Smith, D. P., & Sanderson, M. (2005). Parental pregnancy intention and early childhood stunting: Findings from Bolivia. *International Journal of Epidemiology*, *34*(2), 387–396. https://doi.org/10.1093/ije/dyh354

Shekar, M., Kaktietak, J., Eberwein, J. D., & Walters, D. (2016). *An investment framework for nutrition: Reaching the global targets for stunting, anemia, breastfeeding, and wasting*. Washington, D.C.: The World Bank.

Sobrino, M., Gutierrez, C., Cunha, A. J., Davila, M., & Alarcon, J. (2014). Child malnutrition in children under 5 years of age in Peru: Trends and determinants. *Revista Panamericana de Salud Pública*, *35*(2), 104–112.

Stevens, G. A., Finucane, M. M., De-Regil, L. M., Paciorek, C. J., Flaxman, S. R., Branca, F., … Nutrition Impact Model Study Group (2013). Global, regional, and national trends in haemoglobin concentration and prevalence of total and severe anaemia in children and pregnant and non-pregnant women for 1995–2011: A systematic analysis of population-representative data. *The Lancet Global Health*, *1*(1), e16–e25. https://doi.org/10.1016/S2214-109X(13)70001-9

The National Food Security Bill, Republic of India (2013).

UNICEF–WHO–World Bank Group (United Nations Children's Fund, WHO, and World Bank) (2015). *Joint child malnutrition estimates*. Global Database on Child Growth and Malnutrition.

United Nations Children's Fund (UNICEF) (1990). *Strategy for improved nutrition of children and women in developing countries*. New York: UNICEF.

Valdivia, M.n. (2005). *Peru: Is identifying the poor the main problem in targeting nutritional programs?* World Bank.

Victora, C. G., de Onis, M., Hallal, P. C., Blossner, M., & Shrimpton, R. (2010). Worldwide timing of growth faltering: Revisiting implications for interventions. *Pediatrics*, *125*(3), e473–e480. https://doi.org/10.1542/peds.2009-1519

WHO (2001). *Iron deficiency anaemia assessment, prevention, and control: A guide for programme managers*. Geneva: World Health Organization, UNICEF, UNU.

WHO (2011a). *The global prevalence of anaemia in 2011*. Geneva: World Health Organization.

WHO (2011b). *Haemoglobin concentrations for the diagnosis of anaemia and assessment of severity*. Geneva: World Health Organization.

WHO (2016). *International statistical classification of diseases and health related problems*. Geneva: World Health Organization.

WHO. (2017). Double burden of malnutrition. Retrieved from http://www.who.int/nutrition/double-burden-malnutrition/en/

WHO Multicentre Growth Reference Study Group (2006). WHO child growth standards based on length/height, weight and age. *Acta Paediatrica. Supplement*, *450*, 76–85.

WHO, UNICEF, IFPRI, UC Davis, & USAID (2008). *Indicators for assessing infant and young child feeding practices: Conclusions of a consensus meeting held 6–8 November 2007*. USA: Washington D.C.

World Bank (2006). *Repositioning nutrition as central to development: A strategy for large-scale action*. Washington, D.C.: The World Bank.

World Bank. (2015a). Gross national income per capita 2015, Atlas method and PPP. Retrieved from http://databank.worldbank.org/data/download/GNIPC.pdf

World Bank. (2015b). World development indicators: GINI index. Retrieved from http%3A%2F%2Fdatabank.worldbank.org%2Fdata%2Freports.aspx%3Fsource%3D2%26amp%3Bseries%3DSI.POV.GINI%26amp%3Bcountry=

Young, M., Mehta, R., Gosdin, L., Larson, L., Kekre, K., Verma, P., … Martorell, R. (2017). Impact of home fortification of complementary foods program on child anemia and stunting in Bihar India. *The FASEB Journal*, *31*(1 Supplement), 165–167.

How to cite this article: Gosdin L, Martorell R, Bartolini RM, Mehta R, Srikantiah S, Young MF. The co-occurrence of anaemia and stunting in young children. *Matern Child Nutr*. 2018;14:e12597. https://doi.org/10.1111/mcn.12597