Variation in Anthropometric Status and Growth Failure in Low- and Middle-Income Countries

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abstract

BACKGROUND: Addressing anthropometric failure in low- and middle-income countries can have 2 targets of inference: addressing differences between individuals within populations (W_{pop}) or differences between populations (B_{pop}). We present a multilevel framework to apply both targets of inference simultaneously and quantify the extent to which variation in anthropometric status and growth failure is reflective of undernourished children or undernourished populations.

METHODS: Cross-sectional data originated from the Demographic and Health Surveys program, covering children under age 5 from 57 countries surveyed between 2001 and 2015.

RESULTS: A majority of variation in child anthropometric status and growth failure was attributable to W_{pop}-associated differences, accounting for 89%, 83%, and 85% of the variability in *z* scores for height for age, weight for age, and weight for height. B_{pop}-associated differences (communities, regions, and countries combined) were associated with 11%, 17%, and 15% of the variation in height-for-age *z* score, weight-for-age *z* score, and weight-for-height *z* score. Prevalence of anthropometric failure was closely correlated with mean levels of height and weight. Approximately 1% of W_{pop} variability, compared with 30% to 50% of the B_{pop} variability, was explained by mean values of maternal correlates of anthropometric status and failure. Although there is greater explanatory power B_{pop}, this varied because of modifiability of what constitutes population.

CONCLUSIONS: Our results suggest that universal strategies to prevent future anthropometric failure in populations combined with targeted strategies to address both the impending and existing burden among children are needed.

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Dr Mejía-Guevara conducted data analyses, contributed to the design of the study and interpretation of results, and wrote the first draft of the manuscript; Dr Corsi contributed to the conceptualization and design of the study, data analyses, interpretation, and writing; Drs Perkins and Kim contributed to interpretation and critical revisions to the manuscript; Dr Subramanian conceptualized and designed the study, interpreted the results, contributed to writing, undertook critical revisions, and provided overall supervision; and all authors approved the final manuscript as submitted.

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WHAT'S KNOWN ON THIS SUBJECT: There is conflation of 2 inferential questions, and too often the focus has been on prevention of growth failure and not also on addressing issues for children at high risk or children who are already stunted.

WHAT THIS STUDY ADDS: We consider child anthropometric status and growth failure according to 2 targets of inference: differences between individuals within populations and differences between populations with implications for policy development of both universal and targeted interventions for addressing child growth and nutrition.

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ARTICLE

Anthropometric failure continues to be highly prevalent among children in low- and middle-income countries (LMICs) despite decades of attention to this issue.[1] This situation is concerning, and growth failure in children is known to have irreversible health, social, and economic consequences for both individuals and countries.[2] Presenting a multilevel approach to this problem that incorporates both children and populations is needed to advance strategies that can tackle anthropometric failure globally. Thus, assessing the extent of the possibility for universal strategies to reduce and prevent future anthropometric failure in populations as well as targeted strategies to address the impending and existing burden of anthropometric failure among children at high risk of failure and children who are already stunted is of paramount importance.

In a seminal article titled "Sick Individuals and Sick Populations," Rose[3] contrasted 2 targets of inference to understand variation in health and disease. The first approach was focused on the determinants of health and disease distributions "between individuals within-populations" (W_{pop}), with a focus on the individuals at risk for a particular disease within a population. The second approach was focused on the determinants of health and disease distributions "between populations" (B_{pop}). Understanding the relative importance of the 2 inferential targets (W_{pop} and B_{pop}) has implications for designing evidence-based policy and practice aimed at reducing the variation in disease distribution. For example, inferences drawn from B_{pop} analyses are likely to provide the justification for developing "universal" strategies that apply to all individuals within a population, whereas inferences drawn from a W_{pop} approach are most applicable for developing "targeted" strategies that address individuals at high risk for developing the disease. Each strategy on its own is not sufficient to answer the public health problem presented by global anthropometric failure.

Although factors driving W_{pop} differences may be fundamentally different from the factors driving B_{pop} differences,[4] the methods used to study and address these factors need not occur separately. In this study, we develop a framework to quantify the relative importance of the 2 inferential targets in tandem. We apply W_{pop} and B_{pop} approaches to inform the epidemiologic distribution of anthropometric status and anthropometric failure (hereafter referred to as anthropometric status and failure). Anthropometric status and failure are widely accepted as indicators of growth and nutritional status in children <5 years old and of the burden of chronic and acute undernutrition in populations.[5] Consequently, our study has potential implications for balancing attention between universal and targeted strategies aimed at reducing the distributional burden of anthropometric failure.

We aim to assess the extent to which differences in anthropometric status and failure are attributable to W_{pop} differences and B_{pop} differences when using key maternal and child correlates and other factors associated with socioeconomic status.[6–8] In addition, we provide an integrated framework to assess the following questions from a predictive, rather than causal, perspective: "to what extent can we explain why children vary in their anthropometry?" (ie, explaining W_{pop} differences), and "to what extent can we explain why mean values of anthropometry vary across populations?" (ie, explaining B_{pop} differences).

METHODS

Data

Data for this analysis originated from the most recent nationally representative cross-sectional Demographic and Health Surveys (DHS) Program anthropometric survey conducted in each of 57 countries between 2001 and 2015. The DHS Program focuses on providing indicators of population health and nutrition among women of reproductive age (15–49 years) and their children aged 0 to 59 months.[9] Countries from several continents are included in the DHS Program, including sub-Saharan Africa, South and Southeast Asia, Latin America and the Caribbean, North Africa, and Central Asia. The survey design of DHS is consistent across countries and has been described previously[9,10]; additional details are provided in the Supplemental Information.

Defining Units of Inference: "Individuals" and "Populations"

The W_{pop} units of inference in this study refer to children and their mothers. The B_{pop} units of inference refer to communities, regions, and countries. Communities were defined as the area-based primary sampling units used in DHS. These units typically correspond to census enumeration areas and in many cases capture features of the geographic and socioeconomic structure of populations (eg, a single village or cluster of nearby villages). Standardization of sampling procedures employed in DHS ensured that all primary sampling units were roughly equal in population and enabled a comparative analysis of this unit within and across countries.[9] Regions were defined by using within-country administrative divisions, which aligned with states, provinces, or territories. Such regions are theoretically important levels of variability in child anthropometric status and failure because they represent the level at which policy and health service administration are typically implemented.

Study Population and Sample Size

In DHS, all children <5 years of age living with the index mother are eligible for anthropometric measurement if their household was selected for inclusion in the anthropometry survey. Typically, mothers had between 1 and 2 children available for measurement, and the overall mean in this sample was 1.4 children per mother. In total, surveys enumerated 526 771 children. Our analyses excluded 31 620 children who had died and 137 937 children for whom anthropometric measurements were not available (n = 4968 absent, n = 6316 refused, n = 124 050 because of subsampling for anthropometry or other reasons, and n = 2603 with missing data) (Supplemental Fig 4). We compared the distribution of maternal and child covariates between children who were alive and dead at the time of survey and between those children with and without anthropometric measurements. The samples were highly comparable across covariates and indicated a low risk of bias attributed to excluding these children from the final analytical sample (Supplemental Figs 7 and 8).

We further excluded children on the basis of typically adopted data cleaning criteria for extreme values on anthropometric variables.[11] Children were removed from analyses if height-for-age z score (HAZ) was <−6 or >6 from the World Health Organization growth standards reference median,[11] if weight-for-age z score (WAZ) was <−5 or >5, or if weight-for-height z score (WHZ) was <−5 or >5. These exclusions resulted in the removal of 19 536 children for HAZ and/or stunting, 28 398 for WAZ and/or underweight, and 24 407 for WHZ and/or wasting. A further 13 652 children were excluded for missing values on explanatory factors. The final analytic samples were 324 026 for HAZ and/or stunting, 319 164 for WAZ and/or underweight, and 319 155 for WHZ and/or wasting (Supplemental Fig 4). The total sample represented 57 countries (56 for WAZ and WHZ), between 561 and 583 regions, and ~35 000 communities; and nearly 6000 children on average per country, ~63 per region, 10 per community, and 1.4 per mother (Supplemental Table 1).

Outcomes

Child weight and height or length measurements were obtained by field interview teams. Weight was captured by digital solar-powered scales and height by adjustable ShorrBoard measuring boards designed for use in survey settings. Standing height was obtained for children 24 months and older. In children younger than 24 months, recumbent length was measured with the measuring board placed on a flat surface.

Raw anthropometric data were converted into age- and sex-specific SD units (z scores) by using the World Health Organization child growth standards.[11] This approach is routinely used to give an assessment of child nutritional status B_{pop}.[12] We defined 3 anthropometric status outcomes on the basis of continuous measures of HAZ, WAZ, and WHZ. Anthropometric failure was defined as z scores of <−2 for HAZ (stunting), WAZ (underweight), and WHZ (wasting). Used in combination, these outcomes provide a comprehensive assessment of short-term and/or acute (low weight for age [WA] and low weight for height [WH]) or long-term and/or chronic (low WA, low WH, and low height for age [HA]) undernutrition status in children.[13]

Independent Variables

Maternal independent variables included age, education, and household wealth. Education was categorized by highest level completed: no education, primary school, incomplete secondary, secondary school complete, or higher education. Household wealth was defined as an index of housing characteristics and possession of assets developed separately by country by using principal component analysis and specified in quintiles.[14] The wealth index has been shown to be a robust proxy to long-run household wealth in low-income settings; analytical models used the wealth index as a 5-category ordinal variable on the basis of quintiles. Maternal height and paternal education were included at the child and mother level. Child's age (modeled in continuous months), sex, and location of household (urban or rural) were defined as independent variables.

Statistical Analysis

Multilevel linear regression models were used for the analysis of continuous anthropometric status outcomes, and multilevel logistic regression was used for binary anthropometric failure outcomes. The multilevel approach allows disaggregation of the total variance in the outcome attributable to B_{pop}- and W_{pop}-associated differences accounting for the clustered survey design (further details in Supplemental Information).[15,16] Survey data sets were combined to perform a 5-level multilevel analysis for individual and/or child i (level 1) nested within mother j (level 2), community k (level 3), region l (level 4), and country m (level 5). From the models, variance in the outcome attributed to each population unit was estimated separately and presented as being attributable to W_{pop} (sum of child and mother) associated differences, B_{pop} (sum of community, region, and country) associated differences, or total variance (sum of all units). The ability of independent variables to explain W_{pop}- and B_{pop}-associated differences was assessed by comparing the percentage change in variance attributable to each of the population units from the baseline model (adjusted for age and sex of the child), with a subsequent model that included further explanatory

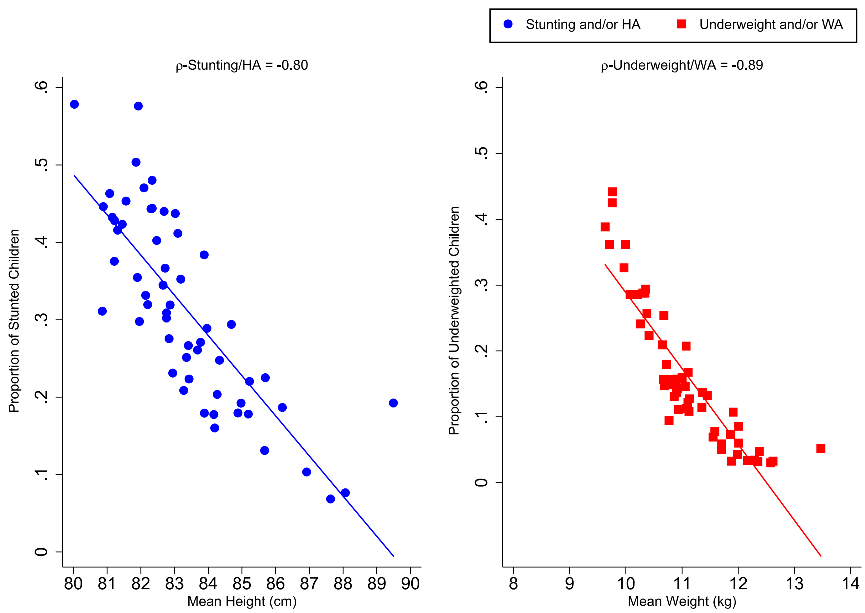

FIGURE 1
Correlation between mean HA and WA and prevalence of children who were stunted (low HA) and underweight (low WA) in 57 LMICs, 2001–2015. ρ, Pearson correlation.

variables (eg, maternal education). All models were estimated by using the command "runmlwin" available in Stata software version 14 (StataCorp, College Station, TX).[17,18]

RESULTS

Across countries, there was a strong and inverse association between the prevalence of anthropometric failure and the mean levels of HA and WA of children (Fig 1). Null models fit for each anthropometric status outcome without independent variables, but including random effects parameters to account for W_{pop}- and B_{pop}-associated differences yielded grand means of −1.24 for HAZ, −0.76 for WAZ, and −0.08 for WHZ. Plotting the 95% coverage bounds around the grand mean indicated the relatively greater W_{pop}-associated differences in outcomes compared with B_{pop}-associated differences (Supplemental Fig 5).

W_{pop}- and B_{pop}-Associated Differences in Anthropometric Status and Failure

In age- and sex-adjusted models, the total variance of HAZ was 2.68. Of the total variance, 85% was attributed to W_{pop}-associated differences (69% attributed to individuals and 16% to mothers), and 15% was attributed to B_{pop}-associated differences (ie, 6%, 4%, and 5% for communities, regions, and countries) (Fig 2). Including the mean values of the other independent variables in the fully adjusted model explained or attenuated B_{pop}-associated variance by 32.5% and total variance by 4.5% (from 2.68 to 2.50). These reductions in B_{pop} and total variance resulted in a corresponding increase in the proportion of total variance in HAZ attributed to W_{pop}-associated differences (from 85% to 89%). WAZ and WHZ followed a similar pattern to HAZ, with 83% and 85% of the total variance attributed to W_{pop}-associated differences, respectively, after adjusting for independent variables (Fig 2, Supplemental Table 2).

Results from analyses of anthropometric failure outcomes were similar. For example, the disaggregated proportions of variation in stunting attributable B_{pop}-associated differences in the fully adjusted model was 4.5% for between-communities, 3.2% for between-regions, and 8.1% for between-countries, whereas the remaining 84% was attributed to W_{pop}-associated differences. Similar patterns were observed for underweight and wasting (Supplemental Fig 6).

B_{pop}-Associated Differences by Communities, Regions, and Countries

The largest share of variation in HAZ attributable to B_{pop}-associated differences was at the country level (41%), followed by communities (37%) and regions (22%) after adjusting for the mean of all independent variables. The shares of variation in WAZ and WHZ attributable to B_{pop}-associated differences were 63% and 53% at the country level, whereas communities accounted for 23% and 32% and regions accounted for 13% and 15% of B_{pop} in WAZ and WHZ, respectively. Including the mean of independent variables (eg, socioeconomic characteristics and maternal height) accounted for 35% and 44% to 48% of B_{pop}-associated differences for communities and regions and 19% to 22% of B_{pop}-associated differences for countries for HAZ and WAZ, respectively. For WHZ, <6% of the B_{pop}-associated differences for communities and regions were explained, but 16% was explained for B_{pop}-associated differences for countries. For all outcomes, regions were associated with the smallest share of B_{pop}-associated differences.

The most important independent variables explaining B_{pop} differences were household wealth (explaining 27%–41% of variation in HAZ and WAZ between communities, regions, and countries) and maternal education (20%–31%), followed by paternal education and maternal height (11%–22%) (Supplemental Table 3). Mean levels of maternal

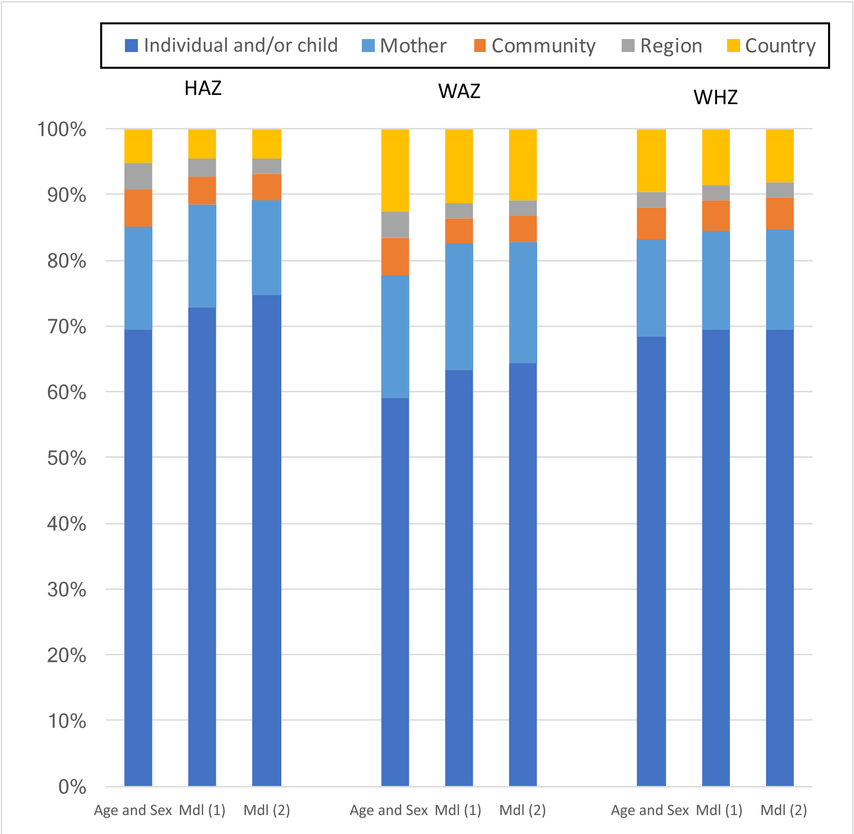

FIGURE 2
Stacked bar showing proportion of total variance in HAZ, WAZ, and WHZ associated with differences W_{pop} (children and mothers), and differences B_{pop} (communities, religions, and countries) in 57 LMICs, 2001–2015. The first bar in each outcome is adjusted for child age and sex. Model 1 was adjusted for child age and sex as well as maternal education, household wealth, and area of residence (urban or rural); Model 2 was adjusted for Model 1 as well as for mother's height, mother's age, and father's education. Mdl, model.

education and household wealth were also important for explaining B_{pop}-associated differences in WHZ but accounted for a smaller proportion of these differences.

We assessed the ability of the mean of each independent variable to explain W_{pop}-associated differences (Supplemental Table 3). Means of maternal, household, and paternal correlates had limited explanatory power and could explain <1% of between-child, W_{pop}-associated differences in HAZ, WAZ, and WHZ. Maternal height accounted for 13% and 8% of between-mother, W_{pop} differences in HAZ and WAZ, but <0.1% for WHZ. In general, the means of the independent variables were better able to explain B_{pop}-associated differences, particularly for HAZ and WAZ. They had only marginal effects in explaining W_{pop}-associated differences, which accounted for most of the total variation in anthropometric status and failure.

Country Differences in Anthropometric Status and Failure

Country-specific analyses of W_{pop}- and B_{pop}-associated differences in anthropometric status indicated that the largest proportion of differences were attributable to W_{pop} differences, accounting for 60% to 91% of total variance in HAZ, 49% to 86% of total variance in WAZ, and 57% to 91% of total variance in WHZ after adjusting for all independent variables (Fig 3). Total variability in anthropometry was inversely correlated with per capita gross domestic product (pcGDP), but the relationship was modest (Pearson correlation = −0.26), with upper-middle income countries demonstrating somewhat less variability W_{pop} compared with low- and lower-middle income countries. On average, ~6% of the variability in anthropometric outcomes across countries was found to be B_{pop} (communities and regions combined). This figure varied from 0.1% to 20.1% for HAZ, with a similar distribution across WAZ and WHZ. The overall proportion of B_{pop}-associated differences in anthropometric status and failure was relatively similar across country groupings on the basis of pcGDP.

DISCUSSION

Using a large cross-comparative data set of children from 57 countries, we have 3 salient findings. First, of the total variation in child anthropometric status, 85% is attributable to W_{pop}-associated differences (combining children and mothers), whereas 15% is attributable to B_{pop}-associated differences (combining communities, regions, and countries). Second, although an overwhelming majority of the variation is attributable to W_{pop} differences, only ~1% is explained by maternal, child, and socioeconomic attributes that are considered major correlates of anthropometric status and failure. In contrast, although a smaller fraction of variation in anthropometric outcomes is attributable to B_{pop}-associated differences, the mean values of maternal and socioeconomic correlates explained 30% to 50% of the B_{pop} variability depending on the definition of population (ie, communities, regions, countries). This ability by the correlates to explain some of the variation indicates clustering in the child and/or maternal correlates by populations. Third, the percentage of variation attributable to W_{pop}-associated differences in anthropometric status and failure that was explained by

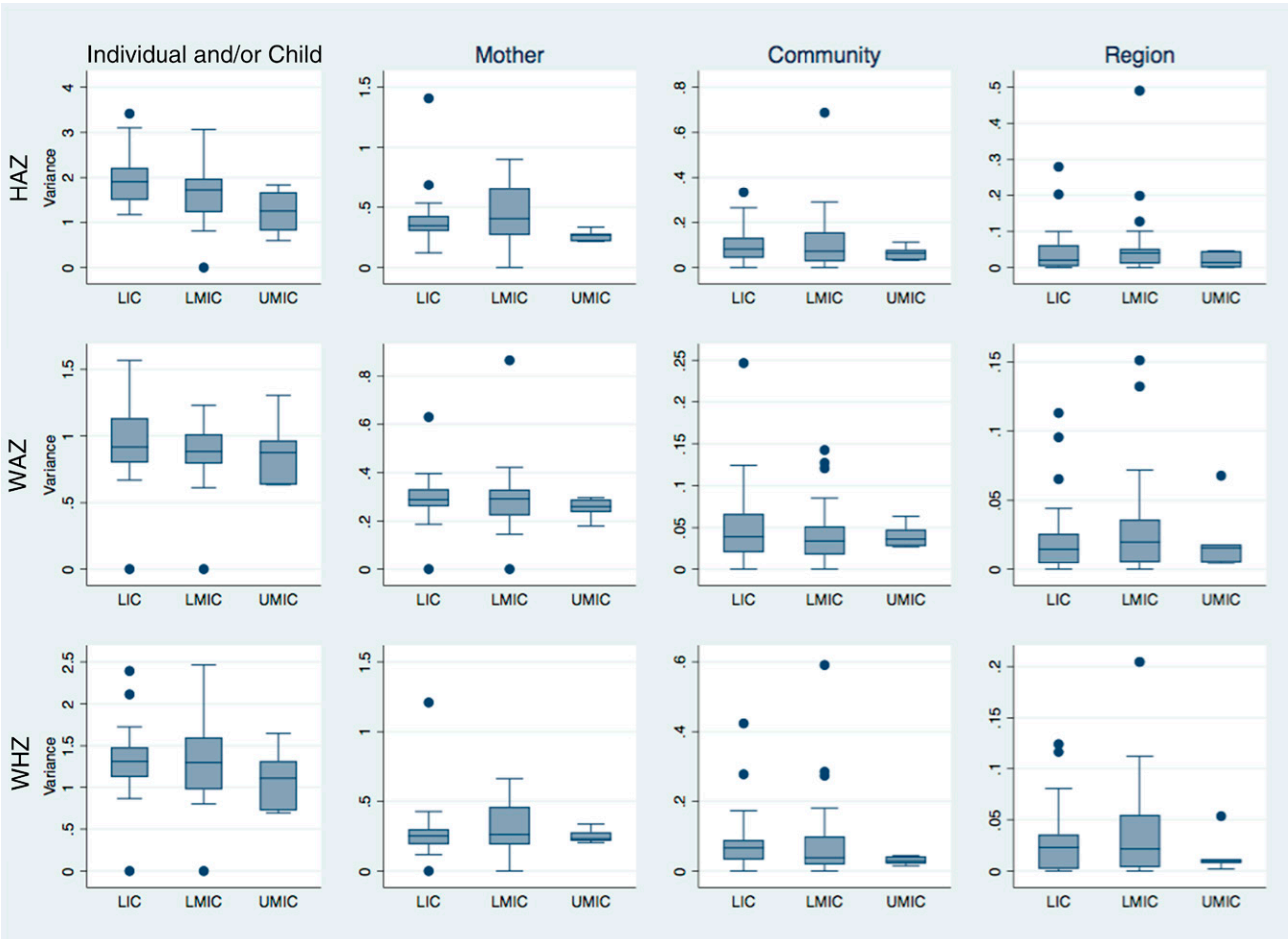

FIGURE 3

Variance in HAZ, WAZ, and WHZ attributed to differences W_{pop} (individual and/or child, mother), and differences B_{pop} (community, region) in 57 LMICs, with countries grouped by pcGDP, 2001–2015. Models were adjusted for child age and sex, maternal education, household wealth, and area of residence. The Pearson correlation between total variance and pcGDP = −0.26. LIC, low-income country (*n* = 28); LMIC (*n* = 23); UMIC, upper-middle income country (*n* = 6).

correlates varied from 0% to 2% across countries, whereas the percent of variation attributable to B_{pop} (communities and regions) associated differences varied from 1% to 20% across countries. These results suggest that the influence of shared environment or broader social factors in shaping the distribution of child anthropometric status and failure may vary by country.

The above findings were consistent across indicators of anthropometric status and failure, although some differences were noted in the W_{pop} and B_{pop} sources of variability for each outcome, which was expected given differences in the underlying biological processes captured by each measure.[19] W_{pop}-associated differences were greatest for HAZ and stunting, markers of long-term accumulation of nutritional status,[5] after adjusting for correlates of anthropometric status and failure. The mean level of maternal height was an important correlate in explaining B_{pop}-associated differences in HAZ and WAZ over and above socioeconomic status. The least amount of variability attributable to W_{pop} or B_{pop} differences in WHZ was explained, indicating that the severe nature of this outcome, which represents short-term acute undernutrition and/or disease, was not well predicted by standard correlates.

These findings have relevance for policies and programming in undernutrition by supporting both universal strategies to benefit anthropometric status of all children and targeted strategies to address existing burdens of anthropometric failure or children at high risk of anthropometric failure. In the context of B_{pop}-associated differences, universal strategies such as improvement in general standards of living and education level at the population level[6,8] can widely benefit the whole population, including children who are not experiencing growth failure, children at risk for failure, and even children who are already experiencing growth failure.[20,21] Such strategies may be difficult to implement in the short term, however. In the context of W_{pop}-associated differences, efforts targeting children at high risk of growth failure through infectious disease treatment and improving environmental conditions for the household are needed and have been effective at improving anthropometric status.[22–24] Finally, strategies for children already suffering from anthropometric failure, such as additional nutritional supplementation and cognitive stimulation,[25,26] may be required to mitigate future consequences of anthropometric failure. Such universal and targeted strategies could be applied simultaneously. Natural variability in anthropometric status and failure will persist within any given population, but improvement in mean levels of anthropometric status through both universal and targeted strategies can lead to reductions in anthropometric failure in populations over time.[27]

Both the amount of variation and the variation explained in our study were different when we considered "populations" as villages as opposed to regions or countries.[28] As the definition of "population" is not straightforward,[29] the challenge of defining population in an appropriate way to reflect underlying risk is important and requires justification; changes to this definition may potentially impact the relationship of risk factors and outcomes between and within populations. Although the importance of assessing B_{pop} differences in health, however, has been established regardless of how populations are defined,[30] the question of providing a clear rationale for defining population is not typically engaged in the literature. Importantly, the statistical methodology we used in this study allows for a relative assessment of many definitions of population, which could be applied in future studies.

The comprehensive amount of detailed anthropometric data and correlates and their comparability across countries are clear advantages of this study, although some data limitations are present. Data quality from DHS is generally high,[31] but anthropometric data can be challenging to collect in field surveys and suffers from greater levels of missingness or incomplete records than other indicators. Many of the "missing" cases arise either by survey design (in which only a subsample is interviewed) or because some children were absent during fieldwork. Missingness due to such scenarios do not necessarily reflect data quality.[32] In addition, racial or ethnic information was not captured in a consistent manner across surveys. The literature reveals that certain health outcomes including birth weight and mortality rates exhibit differing degrees of variability across race and/or ethnic groups,[30] and it is likely that inclusion race and ethnicity in our models would have had some additional ability to explain W_{pop}-associated differences. However, differences due to ethnicity are often considerably attenuated in the presence of socioeconomic status,[33] which, in turn, we do consider in our analysis. The extent to which W_{pop}-associated differences and B_{pop}-associated differences are explained is a function of a data set and the variables the data set may contain. To what extent covariates such as breastfeeding, dietary intake, and access to health services can additionally explain variation needs to be further investigated when comparable data can be obtained. At the same time, the authors of a previous study in India were able to explain only 4%, 12%, and 15% of the variability in WHZ, WAZ, and HAZ, respectively, by adjusting for 15 correlates of child anthropometric status and failure, with socioeconomic correlates accounting for the greatest share.[6]

CONCLUSIONS

Extensive W_{pop}-associated differences in child growth and growth failure were not explained by known correlates of anthropometric status. In contrast, a substantial amount of B_{pop}-associated differences were explained by a clustering of maternal and/or child correlates, and this quantity depended on the definition of population. This analysis of child anthropometric status and failure demonstrates that clear definitions of populations and targets of inference are critical to empirically assess the extent of possibility for interventions to reduce the prevalence of growth failure within populations as well as reduce individual risk for growth failure. Although other population definitions and B_{pop}-associated exposures relevant for anthropometric growth and failure should be conceptualized and measured in future investigations, these findings provide novel support for implementing simultaneous interventions to address anthropometric failure. That is, children at high risk of anthropometric failure need targeted interventions that will mitigate the consequences of suboptimal growth,[6,8,34] and the overall population of both healthy and unhealthy children needs universal interventions to improve general environmental and socioeconomic conditions to increase average anthropometric growth and reduce inequalities B_{pop}.

ABBREVIATIONS

B_{pop}: between populations
DHS: Demographic and Health Surveys
HA: height for age
HAZ: height-for-age *z* score
LMIC: low- and middle-income country
pcGDP: per capita gross domestic product
WA: weight for age
WAZ: weight-for-age *z* score
WH: weight for height
WHZ: weight-for-height *z* score
W_{pop}: between individuals within populations

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