SSM - Population Health 16 (2021) 100965

Contents lists available at ScienceDirect

SSM - Population Health

journal homepage: www.elsevier.com/locate/ssmph

Associations of single versus multiple anthropometric failure with mortality in children under 5 years: A prospective cohort study

Jewel Gausman [a], Rockli Kim [b,c,d], S.V. Subramanian [d,e,*]

[a] Department of Global Health and Population, Harvard T.H. Chan School of Public Health, Boston, MA, USA
[b] Division of Health Policy and Management, College of Health Sciences, Korea University, Seoul, South Korea
[c] Department of Public Health Sciences, Graduate School, Korea University, Seoul, South Korea
[d] Harvard Center for Population and Development Studies, Cambridge, MA, USA
[e] Department of Social and Behavioral Sciences, Harvard T.H. Chan School of Public Health, Boston, MA, USA

ARTICLE INFO

Keywords:
Anthropometric failure
Stunting
Underweight
Wasting
Child health
Nutrition
Child mortality
Young lives
Low and middle income countries
Ethiopia
India
Social disparities
Comprehensive index of anthropometric failure
Categories of anthropometric failure

ABSTRACT

Background/objectives: Stunting, underweight, and wasting are used to monitor nutritional status in children, but they do not identify children with concurrent anthropometric failures (AF). Our study estimates the association between AF and mortality in children with single versus multiple failures, then calculates the percentage of child deaths attributable to AF.

Subjects/methods: Using data from a prospective, longitudinal study of 3605 children from age 1 to age 5 years in Ethiopia and India, we estimate the association between AF and mortality using conventional definitions (stunting, underweight, and wasting) and the mutually exclusive categories of stunted only underweight only, wasted only, stunted and underweight (SU), underweight and wasted, and stunted, underweight, and wasted (SUW), adjusting for socioeconomic status and other demographic variables. Last, we calculate the population attributable fraction.

Results: Children who were SU and SUW had 3.20 (95% CI: 1.69, 6.06; $p < 0.001$) and 5.52 (95% CI: 2.25, 13.56; $p < 0.001$) times the odds of death in fully adjusted models by Round 2 compared to children with no failure, while no increased mortality risk was found among children with other categories of failure. We estimate that 42.69% of child deaths can be attributed to children who are SUW (17.02%) or SU (25.67%), accounting for nearly 80% of child deaths from AF.

Conclusions: This study provides new insight to programs and policy to better identify children most at risk of malnutrition-related mortality.

1. Introduction

Undernutrition and infectious disease are believed to be responsible for more than half of the global burden of under-5 mortality Anthropometric failure (AF), most commonly defined as stunting, underweight, and wasting, is frequently used to assess child nutritional status in the absence of more complete nutritional data. SDG 2 seeks to end hunger and improve nutrition through Target 2.2, which seeks to end all forms of malnutrition, measures progress by tracking the prevalence of stunting (Indicator 2.2.1) and wasting (Indicator 2.2.2).

Previous estimates suggest that stunting, underweight, and wasting between the ages of 1–59 months account for between 14.7% and 17.0%, 14.4% and 17.0%, and 12.6%–11.5% of deaths in children younger than five years. To date, surprisingly few prospective, longitudinal cohort studies have examined the association between AF and all-cause child mortality (Table 1). Many of the key studies that establish this association use the same underlying data derived from a set of cohort studies conducted between 1991 and 2001 (Table 2) (Adair et al., 1993; Alam, Wojtyniak, & Rahaman, 1989; Andersen, 1997; Arifeen et al., 2001; Bairagi, 1981; Fawzi et al., 1997; Garenne, Maire, Fontaine, Dieng, & Briend, September 1987, p. 246, p. 246; Heywood, 1982; Jalil et al., 1993; Katz, WEST Jr, Tarwotjo, & Sommer, 1989; Khan, Jalil, Zaman, Lindblad, & Karlberg, 1993; Kielmann & McCord, 1978; Mølbak et al., 1992; Pelletier, Frongillo Jr, & Habicht, 1993; Ricci & Becker, 1996; Sutrisna, Kresno, Utomo, Reingold, & Harrison, 1993; West Jr et al., 1991; WHO/CHD, 1998; Yambi, Latham, Habicht, & Haas, 1991), and are subject to several important limitations, including inability to account for socioeconomic status (SES). Children living in poverty are at greater risk of AF by way of nutritional deficit and

* Corresponding author. Population Health and Geography, Harvard Center for Population & Development Studies, 9 Bow Street, Cambridge, MA, 02138, USA.
E-mail address: svsubram@hsph.harvard.edu (S.V. Subramanian).

https://doi.org/10.1016/j.ssmph.2021.100965
Received 3 October 2021; Received in revised form 10 November 2021; Accepted 10 November 2021
Available online 17 November 2021

Abbreviations

AF	Anthropometric Failure
CAF	Categories of Anthropometric Failure
CIAF	Composite Index of Anthropometric Failure
HAZ	Height for Age Z-score
LIMCs	Low- and Middle- Income Countries
PAF	Population Attributable Fraction
SES	Socioeconomic Status
SO	Stunted Only
SUW	Stunted, Underweight, and Wasted
UO	Underweight Only
UW	Underweight and Wasted
WAZ	Weight for Age Z-score
WHZ	Weight for Height Z-Score
WO	Wasted Only
YL	Young Lives Study

infectious disease, while also being at higher risk of all-cause mortality.

Much of the existing research on AF and mortality in children is based on conventional indicators that define AF as distinct states of failure (e.g. stunted vs. not stunted, underweight vs. not underweight, and wasted vs. not wasted); however, states of AF are not mutually exclusive and can and do co-occur Children categorized as stunted per the conventional indicator may suffer from either a single failure (stunting only) or multiple failures (stunting *and* underweight, or stunting, underweight *and* wasting) while children who are not considered to be stunted may in fact be underweight and/or wasted. An alternative metric for measuring the overall burden of AF is the Composite Index of Anthropometric Failure (CIAF). The CIAF combines all children experiencing any AF into a single measure by which to estimate the prevalence of undernutrition (Corsi, Subramanyam, & Subramanian, 2011; Nandy, Irving, Gordon, Subramanian, & Smith, 2005; Nandy & Svedberg, 2012; Svedberg, 2000, 2011), though in doing so, it loses the ability to distinguish between specific combinations of multiple and concurrent failures. By disaggregating the CIAF, however, conventional indicators of stunting, underweight and wasting can be classified into seven distinct categories of AF (CAF): stunted only (SO), underweight only (UO), wasted only (WO), stunted and underweight but not wasted)

Table 1
Summary of previous studies that examine the association between anthropometric failure and mortality.

Author	Year	Data	Sample Size	Results by type of Anthropometric Failure			Treatment of Socioeconomic Status (SES)
				Stunting	Underweight	Wasting	
Pelletier	1994	8 cohort studies	28,177 children	Not investigated	Children 70-70% median weight-for-age had 2.5 (2.2, 2.8) times the risk of mortality; children 60–69% of median weight-for-age had 4.6 (3.7, 5.6) times the risk of mortality; children <60% of media weight-for-age had 8.4 (6.3, 11.2) times the risk of mortality compared to children >80% of median weight-for-age.	Not investigated	No adjustment for SES
Caufield et al.	2004	10 cohort studies	Not reported	Not investigated	Children with Z scores < -3 had 8.72 (5.55, 13.72) times the risk of death, children with Z scores between −2 and −3 had 4.24 (3.13, 5.53) times the risk of death, children with Z scores between −1 and −2 had 2.06 (1.77, 2.39) the risk of death compared to children with Z scores > -1.	Not investigated	No adjustment for SES
Black et al.	2008	8 cohort studies	Not reported	Children > -3 Z scores had 4.1 (2.6–6.4) times the odds of death compared to children > -1 Z score. Children > -3 and <-2 had 1.6 (1.3–2.2) times the odds of children > -1 Z score	Children < -3 Z scores had 9.7 (5.2–17.9) times the odds of children > -1 Z score. Children > -3 and <-2 had 2.5 (1.8–3.6) times the odds of death compared to children > -1 Z score. Children > -2 and <-1 had 1.8 (1.2–2.7) times the odds of children > -1 Z score.	Children < -3 Z scores had 9.4 (5.3–16.8) times the odds of children > -1 Z score. Children <-3 and >-2 had 3.0 (2.0–4.5) times the odds of death compared to children > -1 Z score. Children <-2 and >-1 had 1.5 (1.2–1.9) times the odds of children > -1 Z score.	SES markers only available in Nepal and in a separate study in Honduras (not among the studies that contributed data); applied 15% estimated attenuation to other countries' estimates based on results
Olofin et al.	2014	10 cohort studies	53,809 children were eligible and contributed a total of 55,359 person-years.	Pooled mortality HR was 1.46 (1.23–1.74) for children with mild stunting (Z score > -2 and <-1); 2.28 (1.91–2.72) for children with moderate stunting (Z score > -3 and <-2); and 5.48 (4.62–6.50) for children with severe stunting (Z score < -3)	Pooled mortality HR was 1.52 (1.28, 1.81) for mild underweight (Z score > -2 and <-1); 2.63 (2.20, 3.14) for moderate underweight (Z score > -3 and <-2); and 9.40 (8.02, 11.03) for severe underweight (Z score < -3).	Pooled mortality HR was 1.62 (1.41, 1.87) for mild wasting (Z score > -2 and <-1); 3.38 (2.86, 3.98) for moderate underweight (Z score > -3 and <-2); and 11.63 (9.84, 13.76) for severe underweight (Z score < -3).	6 cohorts had variables related to SES (e.g., household assets, mother's education, household water source, and sanitation but the available covariates differed across cohorts). Analysis was performed separately by country and then pooled.

(SU), wasted and underweight but not stunted (WO), and stunted, underweight and wasted (SUW) Children with multiple failures represent a large proportion of the burden of disease in many low- and middle-income countries (LMICs) (Black et al., 2013; Svedberg, 2000, 2011; Vollmer, Harttgen, Kupka, & Subramanian, 2017); however, global interest in concurrence is relatively recent (Wells et al., 2019) and very few studies examine mortality in relation to the CAF. The largest study to explore the association between the CAF and mortality uses the same underlying data as the studies previously cited (Table 2) (Black et al., 2008; Caulfield, de Onis, Blössner, & Black, 2004; Olofin et al., 2013; Pelletier, Frongillo Jr, Schroeder, & Habicht, 1994), and found the highest risk of mortality among children who were SUW, but was unable to account for confounding by SES Inadequate adjustment for SES may result in overestimation of the mortality risk associated with AFs, especially for children experiencing multiple, concurrent AFs. Of note, the combination of stunted and wasted (but not underweight) has been found to be impossible (Myatt et al., 2018).

The purpose of this paper is to provide new estimates of the association between AF and mortality using recent, prospective data from two LMICs to 1) describe the prevalence of different classifications of AF, 2) compare the associations of single and multiple AFs (defined using the conventional indicators of stunting, underweight, wasting, and the CAF) and all-cause mortality, and 3) calculate the population attributable fraction (PAF) to calculate the percentage of child deaths attributable to AF (as measured by CAF) in children under-5 years after accounting for other socioeconomic characteristics in a predominately poor population of children in Ethiopia and India.

2. Materials/subjects and methods

We use secondary data obtained from the younger cohort of children enrolled in the *Young Lives* study (YL) YL is a longitudinal, prospective cohort study conducted in Ethiopia, India, Peru and Vietnam conducted over a 15-year period. YL employed a sentinel site sampling approach whereby 20 sites in each country were selected to ensure geographic diversity and overrepresentation of the poorest communities. Within each site, households with children aged between six and 18 months were eligible and were randomly selected to participate Ethical approval for this study was granted by the London School of Hygiene and Tropic Medicine Ethics Committee along with local institutional review boards in each country and informed consent was taken from parents and/or guardians. For the current study, we use data from the Ethiopia and India cohorts, as the incidence of both AF and child mortality was very low in Peru and Vietnam, with less than 1% of the children in the study dying before the age of 5 years.

Data collection began with Round 1 in 2002. In Round 1, 4010 children aged between 6 and 18 months were enrolled as part of the younger cohort (1999 in Ethiopia and 2011 in India). In the current study, children are followed through Round 2, which occurred in 2006–2007, when the children were aged approximately 5 years.

The outcome of interest is all-cause mortality by Round 2. The exposures of interest are single and multiple AFs defined by stunting (low height-for-age (HAZ)), underweight (low weight-for-age (WAZ)) or wasting (low weight-for-height (WHZ)) at Round 1, and each is defined as less than 2 Z-scores of the WHO child/adolescent reference The exposure categories of stunting, underweight, and wasting were further refined to reflect the mutually exclusive CAF. Supine length at 1 year was measured using standardized length boards to the nearest millimeter and weight was measured calibrated digital balances with 100 g precision.

Other covariates include those that are thought to relate to both AF and mortality, including household SES, characteristics of the child, and parental characteristics including: birth size (based on maternal assessment: small, normal, large), parity, mother's (no education, some primary education, above primary), household wealth (as calculated using three different indices: housing quality, consumer durables and services) (Barnett et al., 2013), rural/urban residence, child's age (in months), and child's sex. Multicollinearity was assessed by examining the variance inflation factors of each variable after running regression models.

Children were eligible to be included in the study if they participated in both Round 1 and Round 2 and had no missing data on the any of the variables included in the study. A total of 1.42% of children (n = 57) were excluded due to attrition between rounds 1 and 2 (1.30% in Ethiopia and 1.54% in India). We found no significant differences between the children who were lost to follow up and those who were included in the study on any of the variables included in the study. Of the 3953 children present in both Round 1 and 2, 5.54% (n = 219) were missing anthropometric data and 5.74% (n = 227) were missing data on other covariates of interest. As a result, a total of 348 (8.8%) children were excluded from the analysis due to missing data.

We first calculated descriptive statistics with regard to the outcomes

Table 2
Summary of data used in previous studies that examine the association between anthropometric failure and mortality.

Original Study Data	Year	Country	Previous Study on AF and Mortality				
			Pelletier (1994)	Caulfield (2004)	Black (2008)	McDonald (2013)	Olofin (2014)
Kielmann and McCord	1978	India	X				
Bairagi	1981	Bangladesh	X				
Heywood	1982	Papua New Guinea	X				
Katz	1989	Indonesia	X			X	X
Alam	1989	Bangladesh	X				
West	1991	Nepal		X	X	X	X
Molbak	1992	Guinea Bissau				X	X
Cogill	1992	Bangladesh	X				
Adair	1993	Philippines			X	X	X
Yambi	1993	Tanzania	X				
Pelletier	1993	N Malawi	X				
Khan	1993	Pakistan		X			
Jalil	1993	Pakistan		X			
Sutrisna	1993	Indonesia		X			
Ricci	1996	Philippines		X			
Fawzi	1997	Sudan		X		X	X
Andersen	1997	Guinea Bissau		X	X		
WHO/CHD	1998	Ghana		X		X	X
WHO/CHD	1998	India		X	X	X	X
WHO/CHD	1998	Peru				X	X
Garenne	2000	Senegal		X	X	X	X
Arifeen	2001	Bangladesh		X	X	X	X

of interest, exposures, and related covariates for each country individually and pooled across study sites. Second, we fit separate logistic models examining different exposure categories, 1) stunted (vs. not stunted), 2) underweight (vs. not underweight), 3) wasted (vs. not wasted), and 4) SO, UO, WO, SU, UW, and SUW (vs. no failure). For each of these exposure categories, we fit three sequential models 1) unadjusted, 2) adjusted for SES, and 3) fully adjusted for all covariates. SES-adjusted models include wealth quintile, mother's educational attainment, and rural/urban location. All models include country-level fixed effects to take into account unmeasured differences related to study site. We compare the percentage difference between the crude and SES-adjusted odds to examine the magnitude of confounding by SES. Last, we calculate the PAF for each country and pooled across countries using the formula:

$$PAF = \frac{p_{pop}*(RR-1)}{p_{pop}*(RR-1)+1}$$

where p_{pop} is the proportion of children exposed to a type of AF and RR is the adjusted risk ratio.

3. Results

The final sample used in the analysis includes 3522 children (1702 in Ethiopia and 1903 in India). Supplemental Table 1 provides the overall distribution of children by socioeconomic and demographic characteristics, as well as the distribution of AF by these covariates. Overall, the sample consisted of 46.96% girls and 53.04% boys. The majority of mothers had no education (61.97%; n = 2169). The majority of children, 70.10% (n = 2527) lived in rural areas. Table 3 shows that overall, 1.85% (n = 67) of children in the sample died by Round 2 (2.46% in Ethiopia and 1.31% in India). At Round 1, 36.11% (n = 1302) children were stunted (42.00% in Ethiopia and 30.84% in India), 33.95% (n = 1188) were underweight (33.43% in Ethiopia and 32.52% in India) and 17.83% (n = 643) were wasted (14.98% in Ethiopia and 20.39% in India). In examining the CAF, the majority of children were SU (17.80%; n = 642), followed by SO (13.31%; n = 480). Among children with multiple failures, UW was the second most common with 7.52% (n = 271) of children (6.11% in Ethiopia and 8.78% in India). Nealy 5% of children were SUW overall, with 5.40% (n = 92) and 4.62% (n = 88) of children in Ethiopia and India, respectively, experiencing all three failures simultaneously.

In our study population, the most disadvantaged children were more likely to experience AF. Children who were stunted, underweight, or wasted were more likely to be from the poorest households. Overall, 26.19% of stunted children were from the poorest wealth quintile versus 12.06% amongst the richest. Similarly, 27.19% and 22.40% of children who were underweight and wasted were from the poorest wealth quintile versus 14.39% and 19.44% amongst the richest, respectively.

Table 4 presents the proportion of children who died by Round 2 according to each type of AF. For each of the conventional AFs, a larger proportion of children with the failure died than those without the failure: 3.15% of children who were stunted died compared to 1.13% of children who were not stunted, 2.95% of children who were underweight died compared to 1.32% of children who were not underweight, and 2.02% of children who were wasted died compared to 1.82% of children who were not wasted. With regard to the CAF, the largest proportion of deaths occurred among children who suffered from multiple, concurrent AFs as opposed to single AFs. Among children who were SUW, 4.44% died by Round 2, and among children who were SU, 3.58% died by Round 2. The proportion of deaths amongst children who were SUW and SU were higher in Ethiopia than in India. In comparison, among children with a singular failure, 2.08% of SO children, 1.05% of UO children, and 1.04% of WO children died by Round 2.

Table 5 presents the results from the unadjusted, SES adjusted, and fully adjusted regression models. No variables were omitted from the model due to multicollinearity as all VIFs were less than 10. After adjusting for all covariates, children who were stunted had 2.87 times the odds of death by Round 2 compared to children who were not stunted (95% CI: 1.71, 4.48; $p < 0.001$), and children who were underweight had 2.25 times the odds of death compared to children who were not underweight (95% CI: 1.35, 3.74; $p < 0.01$). With regard to the CAF, only children who were SUW and SU had significantly higher odds of death compared to children who had no failure. Children who were SUW had 5.52 times of odds and of death by Round 2 (95% CI: 2.25, 13.56; $p < 0.001$) and children who were SU had 3.20 times the odds of death by Round 2 (95% CI: 1.69, 6.06; $p < 0.001$) compared to children with no failure. We do not find evidence for an increased risk of mortality among children who are SO, UO, WO or UW. In all models, there is a strong gradient observed with regard to the risk of death according to wealth quintile; children from the wealthiest households had a significantly lower risk of death. We also find evidence that SES confounds the association between mortality and AF. We find a greater than 10% attenuation in the estimated odds of mortality associated with AF comparing the crude versus the SES-adjusted models for all of the significant effects (15% for stunting, 13% for underweight 14% for SU, and 12% for SUW). The full regression results can be found in Supplemental

Table 3
Distribution of mortality by age 5, single anthropometric failure, and multiple anthropometric failure in Ethiopia and India.

	Ethiopia (n = 1702)	India (n = 1903)	Total (n = 3605)
Died by age 5	2.46 (42)	1.31 (25)	1.85 (67)
Stunted	42.00 (715)	30.84 (587)	36.11 (1302)
Underweight	33.43 (569)	32.52 (619)	33.95 (1188)
Wasted	14.98 (255)	20.39 (388)	17.83 (643)
Categories of Anthropometric Failure			
No failure	46.47 (791)	50.13 (954)	48.41 (1745)
Stunted Only (SO)	16.62 (283)	10.35 (197)	13.31 (480)
Underweight Only (UO)	1.94 (33)	3.26 (62)	2.64 (95)
Wasted Only (WO)	3.47 (59)	6.99 (133)	5.32 (192)
Stunted and Underweight (SU)	19.98 (340)	15.86 (302)	17.80 (642)
Underweight and wasted (UW)	6.11 (104)	8.78 (167)	7.52 (271)
Stunted, underweight and wasted (SUW)	5.40 (92)	4.62 (88)	4.99 (180)

Table 4
Percentage of children who died by round 2 according to type of anthropometric failure.

	% Died by Round 2		
	Ethiopia	India	Total
Stunted			
No	1.32 (13)	0.99 (13)	1.13 (26)
Yes	4.06 (29)	2.04 (12)	3.15 (41)
Underweight			
No	1.77 (20)	0.93 (12)	1.32 (32)
Yes	3.87 (22)	2.10 (13)	2.95 (35)
Wasted			
No	2.35 (34)	1.32 (20)	1.82 (54)
Yes	3.14 (8)	1.29 (5)	2.02 (13)
CAF			
No failure	1.26 (10)	1.05 (10)	1.15 (20)
Stunted only	3.18 (9)	0.51 (1)	2.08 (10)
Underweight only	0.00 (0)	1.61 (1)	1.05 (1)
Wasted only	1.69 (1)	0.75 (1)	1.04 (2)
Stunted and underweight	4.41 (15)	2.35 (8)	3.58 (23)
Underweight and wasted	1.92 (2)	0.60 (1)	1.11 (3)
Stunted, underweight, and wasted	5.43 (5)	3.41 (3)	4.44 (8)
Total	2.47 (42)	1.31 (25)	1.86 (67)

Table 5
Unadjusted and Multivariable Adjusted Logistic Regression Analysis of Mortality Under Age Five Years on Single vs. Multiple Anthropometric Failures (AF).

Type of Anthropometric Failure	Unadjusted	SES Adjusted[a]	Fully Adjusted[b]
Stunted (ref: not stunted)	2.678*** (1.625–4.413)	2.447*** (1.472–4.067)	2.866*** (1.705–4.819)
Underweight (re: not underweight)	2.252*** (1.386–3.657)	2.048*** (1.242–3.377)	2.248*** (1.352–3.736)
Wasted (ref: not wasted)	1.180 (0.639–2.181)	1.119 (0.603–2.076)	1.334 (0.709–2.509)
Categories of AF (Ref: no failure)			
Stunted Only	1.708 (0.792–3.684)	1.605 (0.741–3.477)	1.941 (0.887–4.247)
Underweight Only	0.974 (0.129–7.350)	0.918 (0.121–6.954)	0.674 (0.0882–5.142)
Wasted Only	0.987 (0.228–4.268)	0.989 (0.228–4.291)	1.178 (0.270–5.148)
Stunted and Underweight	3.081*** (1.678–5.656)	2.762*** (1.479–5.158)	3.201*** (1.692–6.056)
Underweight and Wasted	1.004 (0.296–3.405)	0.930 (0.272–3.178)	1.193 (0.345–4.125)
Stunted, Underweight and Wasted	3.897*** (1.689–8.991)	3.455*** (1.476–8.087)	5.521*** (2.248–13.56)

***P < 0.001, **p < 0.01, *p < 0.05; 95% CI in parentheses.
[a] Socioeconomic status (SES) Adjusted Models include wealth quintile, mother's education, father's education and place of residence (rural/urban).
[b] Fully Adjusted Models include SES variables + child's age in months, child's sex, birth size, mother's parity, and months of breastfeeding.

Table 2.

The PAF is presented in Table 6. Overall, across both countries, we estimate that 42.69% of child deaths can be attributed to children who are SUW (17.02%) or SU (25.67%). Thus, overall, nearly 80% of child deaths from AF may be attributed to children in these two categories. In Ethiopia, 46.73% of child deaths are attributable to SUW (17.96%) and SU (28.77%), while in India, 41.18% of child deaths are attributable to SUW (16.27%) and SU (24.91%). Fig. 1 illustrates the magnitude of the differences of child deaths attributable to different categories of failure.

4. Discussion

The results of this study contribute new findings regarding the association between mortality, SES and AF. In particular, our results show that children with multiple, concurrent failures, specifically children who are SU and SUW according to the CAF, are at the greatest risk of mortality. Further, we argue that the overlapping categories of stunting, underweight, and wasting may be too broad, and as such, may not accurately identify the children at greatest risk of mortality due to AF.

While our results replicate those of previous studies which suggest that children who are stunted or underweight, as conventionally defined, have an increased risk or mortality compared to those who are not stunted or not underweight, our analysis of the CAF suggests that the increased risk of mortality observed among stunted or underweight children may in fact be concentrated among children within those failure categories who simultaneously suffer from another failure. This conclusion is supported by the fact that we find no evidence for increased risk of mortality among children who are either only stunted or only underweight. To build on these findings, an important area for future research is to explore whether there may be an interaction between the presence of multiple, concurrent failures and the severity of a given failure, given that past research suggests that the risk of death associated with a given failure has been found to increase with the severity of a failure.

Table 6
Population Attributable Fraction for the Effect of Anthropometric Failure (AF) as per the Categories of AF (CAF) on Child Mortality vs. No Failure.

Category of Anthropometric Failure	Population Attributable Fraction (95% CI)		
	Ethiopia	India	Total
Stunted Only	12.92 (−1.92, 33.64)	8.58 (−1.21, 24.26)	10.55 (−1.52, 28.72)
Underweight Only	−0.70 (−1.97, 7.87)	−1.07 (−3.06, 11.59)	−0.91 (−2.57, 9.98)
Wasted Only	0.61 (−2.36, 11.44)	1.31 (−5.25, 21.82)	1.00 (−3.95, 17.54)
Stunted and Underweight	28.77 (11.44, 47.69)	24.91 (9.59, 42.82)	26.67 (10.42, 45.09)
Underweight and Wasted	1.15 (−4.54, 16.57)	1.49 (−5.99, 20.53)	1.34 (−5.34, 18.83)
Stunted, Underweight, and Wasted	17.96 (6.02, 36.72)	16.27 (5.38, 33.99)	17.02 (5.66, 35.23)

Our calculation of the PAF suggests that a substantial proportion of child deaths could be prevented by addressing certain combinations of AF – specifically, children who are SU or SUW, despite these children constituting a relatively small percentage of the population. Thus, focusing intervention efforts on children who experience AF in specific combinations, rather than on children who are identified to be at risk by way of the conventional indicators, may lead to more effective and efficient programs that offer a greater reduction in child mortality. More research is needed to better understand the determinants of the different CAF in order to inform prevention strategies.

Traditionally, stunting, underweight, and wasting have been thought to reflect different etiologies, and thus require different interventions In general, stunting is often considered to be insensitive to short-term nutritional deficit while underweight and wasting are usually considered to result from acute starvation and/or infectious diseases However, this bifurcated understanding may have contributed to an unnecessary fragmentation in policy and programs (Fentahun, Belachew, & Lachat, 2016; Nandy & Jaime Miranda, 2008; Wells et al., 2019), that according to our results, may be somewhat misaligned with the burden of disease. More recent research has found stunting, underweight, and wasting to share many of the same underlying causes A recent literature review was unable to find any unique causes of wasting that were not also associated with stunting More research to better understand the underlying factors that contribute to multiple, simultaneous AFs in children would enable programs to better address health and nutrition outcomes among children in this particularly vulnerable state.

Our study also contributes to a deeper understanding of the role that SES plays in the association between mortality and AF in children, an issue that has not been fully explored in previous studies. The YL study was designed to over-represent the poorest communities in each country To this point, we found that in our study population, SU was the most common CAF, followed by SO. These results contrast with those of other population-based studies which have found that globally, SO is the most common type of AF Previous research has suggested that multiple concurrent failures are more common among children from poorer households The fact that our study population is comprised primarily of poor households further reduces the risk of confounding by SES due to unmeasured variables, although we still find evidence for confounding by SES despite our largely-poor study sample. Other studies that have examined linear growth in children using the same data have found evidence of a wealth gradient Taken together, these results emphasize the importance of addressing the potential for confounding by SES when exploring the association between AF and mortality, as even a greater degree of confounding by SES could be present in a study with a more representative population than what was observed in our study. Confounding by SES may be one reason why our results differ from the aforementioned meta-analysis that did not include SES variables, which found that children who were SO, SU, UW, and SUW had a heightened risk of mortality (McDonald et al., 2013), while in our study, we do not find a significant association between mortality and AF among children who are SO and UW.

This study has several strengths and limitations. Among its strengths, this study ascertains anthropometric status between 6 and 18 months in

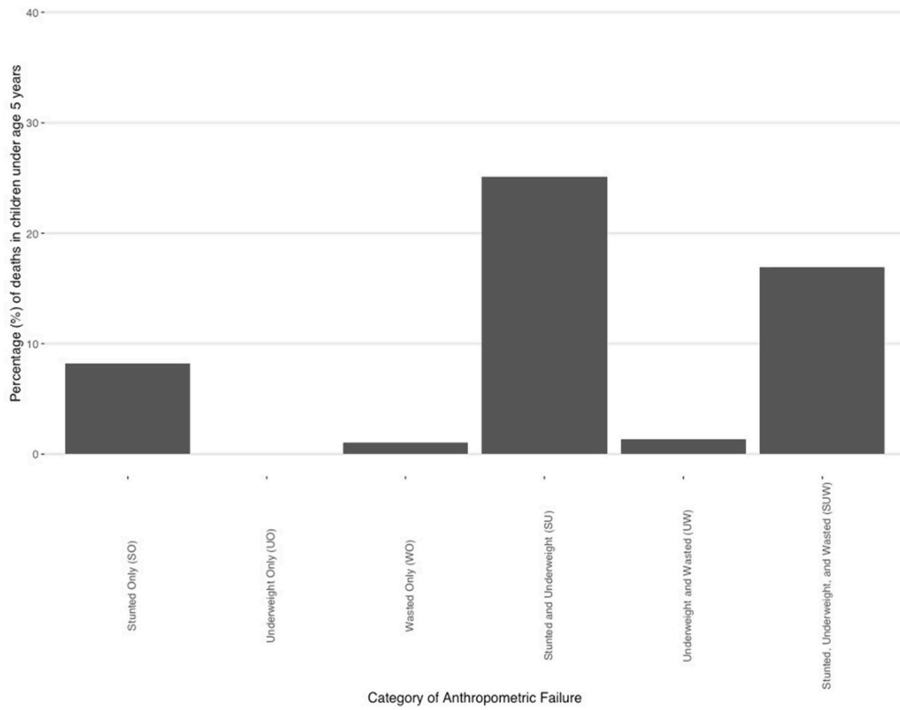

Fig. 1. Percentage of deaths in children under-5 years attributable to different categories of anthropometric failure (AF).

Round 1 and follows a large sample of children through a mean of 63 months (5.25 years of age). Our study does not consist of a birth cohort, thus we are unable to assess mortality in the period prior to enrollment; however, several other prospective cohort studies which form the existing base of the literature on AF and mortality enrolled children several months to years after birth (Fawzi et al., 1997; Katz, WEST, Tarwotjo, & Sommer, 1989; McDonald et al., 2013; West Jr et al., 1991). The few existing studies that examine the association between single and multiple AFs follow the majority of children for a much shorter duration. In terms of limitations, our study is unable to determine causality. We do not have the exact dates of death, thus we are unable to examine the outcome with regard to time-to-event. Further, we do not know the child's anthropometric status immediately prior to death. The high level of poverty of the study population may also reduce generalizability. Last, certain combinations of AF and death in the study population were rare and despite a relatively large study population, few children died before the age of 5, which may have limited our ability to fully explore some of the rarer exposure categories. Finally, we do not have nutritional data available, thus we cannot specifically assess malnutrition directly, and we further recognize that AF can also result from infectious disease. Furthermore, the data were collected in 2006; however, they provide an update to existing to the existing body of literature. Other studies using the same data as ours have highlighted the important role that improved sanitation plays in reductions in stunting. However, given that stunting and wasting, in particular, are recognized global indicators that are often used as indirect measures of child nutritional status in the absence of such data, we believe that our findings are relevant to the study of nutrition-related mortality in children.

The results of this study add to recent calls to take a more integrated approach to understanding the causes and consequences of undernutrition and mortality related to AF. With our results, we do not intend to detract from a continued focus on reducing stunting, underweight, and wasting, as these failures are associated with significant long-term consequences related to health, education, and economic potential, among other outcomes We believe, however, that our results indicate that an overreliance on the conventional indicators of stunting, underweight, and wasting may overstate progress in addressing malnutrition and other causes of child mortality if programs are more easily able to address children with single AFs, thereby obscuring the burden of disease among the children who suffer from multiple AFs who are at a greater risk of death. This study provides new insight to programs and policy to programs seeking to address children most at risk of mortality related to AF. Further research is needed to support programs in addressing the needs of children who suffer from multiple AFs, especially in identifying the etiology of such conditions and ways to improve both prevention and treatment.

Conflict of interests disclosures

The authors have no conflicts of interest relevant to this article to disclose.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author contributions

JG performed the analysis, led the interpretation of the findings, and wrote the first draft of the manuscript, RK provided critical input to the analysis and manuscript drafts, SVS conceptualized the study and provided overall supervision.

Ethical statement

We used secondary data obtained from the younger cohort of children enrolled in the Young Lives study (YL). The data were not collected specifically for this study and no one on the study team has access to identifiers linked to the data. These activities do not meet the regulatory definition of human subjects research. As such, IRB review is not required.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2021.100965.

References

Adair, L., Popkin, B. M., VanDerslice, J., Akin, J., Guilkey, D., Black, R. E., … Flieger, W. (1993). Growth dynamics during the first two years of life: A prospective study in the Philippines. *European Journal of Clinical Nutrition, 47*(1), 42–51.

Alam, N., Wojtyniak, B., & Rahaman, M. M. (1989). Anthropometric indicators and risk of death. *American Journal of Clinical Nutrition, 49*(5), 884–888.

Andersen, M. (1997). *Anthropometric measurements in health programmes: Epidemiological and statistical aspects: PhD-thesis*. Marc Andersen.

Arifeen, S., Black, R. E., Antelman, G., Baqui, A., Caulfield, L., & Becker, S. (2001). Exclusive breastfeeding reduces acute respiratory infection and diarrhea deaths among infants in Dhaka slums. *Pediatrics, 108*(4). e67-e67.

Bairagi, R. (1981). On validity of some anthropometric indicators as predictors of mortality. *American Journal of Clinical Nutrition, 34*(11), 2592–2594.

Barnett, I., Ariana, P., Petrou, S., Penny, M. E., Duc, L. T., Galab, S., … Boyden, J. (2013). Cohort profile: The young Lives study. *International Journal of Epidemiology, 42*(3), 701–708.

Black, R. E., Allen, L. H., Bhutta, Z. A., Caulfield, L. E., De Onis, M., Ezzati, M., … Group, C. U. S. (2008). Maternal and child undernutrition: Global and regional exposures and health consequences. *The Lancet, 371*(9608), 243–260.

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., de Onis, M., … Martorell, R. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet, 382*(9890), 427–451. Retrieved from http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(13)60937-X/abstract.

Caulfield, L. E., de Onis, M., Blössner, M., & Black, R. E. (2004). Undernutrition as an underlying cause of child deaths associated with diarrhea, pneumonia, malaria, and measles. *American Journal of Clinical Nutrition, 80*(1), 193–198. https://doi.org/10.1093/ajcn/80.1.193

Corsi, D. J., Subramanyam, M. A., & Subramanian, S. (2011). Commentary: Measuring nutritional status of children. *International Journal of Epidemiology, 40*(4), 1030–1036.

Fawzi, W. W., Herrera, M. G., Spiegelman, D. L., El Amin, A., Nestel, P., & Mohamed, K. A. (1997). A prospective study of malnutrition in relation to child mortality in the Sudan. *American Journal of Clinical Nutrition, 65*(4), 1062–1069.

Fentahun, N., Belachew, T., & Lachat, C. (2016). Determinants and morbidities of multiple anthropometric deficits in southwest rural Ethiopia. *Nutrition, 32*(11), 1243–1249. https://doi.org/10.1016/j.nut.2016.03.023

Garenne, M., Maire, B., Fontaine, O., Dieng, K., Briend, A., & September. (1987). *Risques de décès associés à différents états nutritionnels chez l'enfant d'Âge préscolaire [Risks of dying associated with different nutritional status in pre-school aged children]* (Rapport final. Retrieved from).

Heywood, P. (1982). Functional significance of malnutrition–growth and prospective risk of death in the highlands of Papua New Guinea. *Journal of food and nutrition*.

Jalil, F., Lindblad, B. S., Hanson, L., Khan, S., Ashraf, R., Carlsson, B., … Karlberg, J. (1993). Early child health in Lahore, Pakistan: I. Study design. *Acta Paediatrica, 82*, 3–16.

Katz, J., West, K. P., Jr., Tarwotjo, I., & Sommer, A. (1989). The importance of age in evaluating anthropometric indices for predicting mortality. *American Journal of Epidemiology, 130*(6), 1219–1226.

Khan, S., Jalil, F., Zaman, S., Lindblad, B., & Karlberg, J. (1993). Early child health in Lahore, Pakistan: X. Mortality. *Acta Paediatrica, 82*, 109–117.

Kielmann, A., & McCord, C. (1978). Weight-for-age as an index of risk of death in children. *The Lancet, 311*(8076), 1247–1250.

McDonald, C. M., Olofin, I., Flaxman, S., Fawzi, W. W., Spiegelman, D., Caulfield, L. E., … Study, N. I. M. (2013). The effect of multiple anthropometric deficits on child mortality: meta-analysis of individual data in 10 prospective studies from developing countries. *American Journal of Clinical Nutrition, 97*(4), 896–901.

Mølbak, K., Aaby, P., Ingholt, L., Højlyng, N., Gottschau, A., Andersen, H., … Vollmer, A. (1992). Persistent and acute diarrhoea as the leading causes of child mortality in urban Guinea Bissau. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 86*(2), 216–220.

Myatt, M., Khara, T., Schoenbuchner, S., Pietzsch, S., Dolan, C., Lelijveld, N., et al. (2018). Children who are both wasted and stunted are also underweight and have a high risk of death: A descriptive epidemiology of multiple anthropometric deficits using data from 51 countries. *Archives of Public Health, 76*(1), 28.

Nandy, S., Irving, M., Gordon, D., Subramanian, S., & Smith, G. D. (2005). Poverty, child undernutrition and morbidity: New evidence from India. *Bulletin of the World Health Organization, 83*, 210–216.

Nandy, S., & Jaime Miranda, J. (2008). Overlooking undernutrition? Using a composite index of anthropometric failure to assess how underweight misses and misleads the assessment of undernutrition in young children. *Social Science & Medicine, 66*(9), 1963–1966. https://doi.org/10.1016/j.socscimed.2008.01.021

Nandy, S., & Svedberg, P. (2012). The Composite Index of Anthropometric Failure (CIAF): An alternative indicator for malnutrition in young children. In *Handbook of anthropometry* (pp. 127–137). Springer.

Olofin, I., McDonald, C. M., Ezzati, M., Flaxman, S., Black, R. E., Fawzi, W. W., … Study, N. I. M. (2013). Associations of suboptimal growth with all-cause and cause-specific mortality in children under five years: A pooled analysis of ten prospective studies. *PLoS One, 8*(5), Article e64636.

Pelletier, D. L., Frongillo, E. A., Jr., & Habicht, J.-P. (1993). Epidemiologic evidence for a potentiating effect of malnutrition on child mortality. *American Journal of Public Health, 83*(8), 1130–1133.

Pelletier, D. L., Frongillo, E. A., Jr., Schroeder, D. G., & Habicht, J.-P. (1994). A methodology for estimating the contribution of malnutrition to child mortality in developing countries. *Journal of Nutrition, 124*(suppl_10), 2106S–2122S.

Ricci, J. A., & Becker, S. (1996). Risk factors for wasting and stunting among children in Metro Cebu, Philippines. *American Journal of Clinical Nutrition, 63*(6), 966–975.

Sutrisna, B., Kresno, S., Utomo, B., Reingold, A., & Harrison, G. (1993). Care-seeking for fatal illnesses in young children in Indramayu, west Java, Indonesia. *The Lancet, 342*(8874), 787–789.

Svedberg, P. (2000). *Poverty and undernutrition: Theory, measurement, and policy*. New York: Oxford University Press.

Svedberg, P. (2011). How many people are malnourished? *Annual Review of Nutrition, 31*, 263–283.

Vollmer, S., Harttgen, K., Kupka, R., & Subramanian, S. (2017). Levels and trends of childhood undernutrition by wealth and education according to a composite index of anthropometric failure: Evidence from 146 demographic and health Surveys from 39 countries. *BMJ global health, 2*(2), Article e000206.

Wells, J. C., Briend, A., Boyd, E. M., Berkely, J. A., Hall, A., Isanaka, S., … Dolan, C. (2019). *Beyond wasted and stunted—a major shift to fight child undernutrition*. The Lancet Child & Adolescent Health.

West, K. P., Jr., Katz, J., Leclerq, S. C., Pradhan, E. K., Tielsch, J. M., Sommer, A., … Pandey, M. (1991). Efficacy of vitamin A in reducing preschool child mortality in Nepal. *The Lancet, 338*(8759), 67–71.

WHO/CHD. (1998). Randomised trial to assess benefits and safety of vitamin A supplementation linked to immunisation in early infancy. WHO/CHD Immunisation-Linked Vitamin A Supplementation Study Group. *Lancet, 352*(9136), 1257–1263.

Yambi, O., Latham, M. C., Habicht, J.-P., & Haas, J. D. (1991). Nutrition status and the risk of mortality in children 6–36 months old in Tanzania. *Food and Nutrition Bulletin, 13*(4), 1–6.