# Quantifying the fatal and non-fatal burden of disease associated with child growth failure, 2000-2023: a systematic analysis from the Global Burden of Disease Study 2023.

GBD 2023 CHILD GROWTH FAILURE COLLABORATORS

# Quantifying the fatal and non-fatal burden of disease associated with child growth failure, 2000–2023: a systematic analysis from the Global Burden of Disease Study 2023

*GBD 2023 Child Growth Failure Collaborators**

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## Summary

**Background** Child growth failure (CGF), which includes underweight, wasting, and stunting, is among the factors most strongly associated with mortality and morbidity in children younger than 5 years worldwide. Poor height and bodyweight gain arise from a variety of biological and sociodemographic factors and are associated with increased vulnerability to infectious diseases. We used data from the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2023 to estimate CGF prevalence, the risk of infectious diseases associated with CGF, and the disease mortality, morbidity, and overall burden associated with CGF.

**Methods** In this analysis we estimated the all-cause and cause-specific (diarrhoea, lower respiratory tract infections, malaria, and measles) disability-adjusted life-years (DALYs) lost and mortality associated with stunting, wasting, underweight, and CGF in aggregate. We combined the burden associated with mild, moderate, and severe forms of CGF: stunting was defined as height-for-age Z scores (HAZ) less than –1, underweight was defined as weight-for-age Z scores (WAZ) less than –1, and wasting was defined as weight-for-height Z scores (WHZ) less than –1, according to WHO Child Growth Standards. Population-level continuous distributions of HAZ, WAZ, and WHZ were estimated for 2000 to 2023 using data from surveys, literature, and individual-level study data. The risk of incidence of, and mortality due to, diarrhoea, lower respiratory infections, malaria, and measles was separately estimated in a meta-regression framework from longitudinal cohort data for Z scores less than –1. Finally, fatal outcomes associated with these diseases were estimated with vital registration, verbal autopsy, and case-fatality data, while non-fatal outcomes were estimated with surveys as well as health-care utilisation and case reporting data. The exposure prevalence and relative risk estimates were from continuous distributions, allowing for direct assessment of the attributable fractions for mild, moderate, and severe stunting, underweight, wasting, and the combined impact of child growth failure within populations. All estimates were age-specific, sex-specific, geography-specific, and year-specific.

**Findings** We estimated that, in children younger than 5 years in 2023, CGF was associated with 79·4 million (95% uncertainty interval [UI] 47·0–106) DALYs lost and 880 000 (517 000–1 170 000) deaths. This represented 17·9% (10·6–23·8) of 444 million (434–457) total under-5 DALYs and 18·8% (11·1–25·0) of all 4·67 million (4·59–4·75) under-5 deaths. Compared to stunting (33·0 million [24·1–42·2] DALYs, 373 000 [272 000–477 000] deaths) and wasting (39·2 million [23·8–53·0] DALYs, 428 000 [256 000–583 000] deaths), childhood underweight was associated with the largest share of CGF-related disease burden: 52·2 million (21·9–75·1) DALYs and 573 000 (236 000–824 000) deaths in children younger than 5 years in 2023.

**Interpretation** CGF remains a leading factor associated with death and disability in children younger than 5 years, despite global attention and focused interventions to reduce the prevalence of associated CGF indicators. Our findings underscore the need for policies, strategies, and interventions that focus on all indicators of CGF to reduce its associated health burden.

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## Introduction

Child growth failure (CGF), characterised by poor linear height and bodyweight gain, represents a complex interplay of nutritional, maternal, developmental, socio-economic, environmental, and health-care factors.[1] Children who experience growth failure have a greater infectious disease burden, including risk of mortality, than those who do not.[2–5] CGF is associated with lifelong consequences such as cognitive and metabolic impairment, which might contribute to poorer educational performance and lost opportunities.[1,6] Therefore, quantifying its prevalence and associated

## Research in context

### Evidence before this study

Even with decades of substantial global investment, child growth failure (CGF) remains a leading risk factor associated with death and disability in children younger than 5 years. In the most recent global estimates of CGF burden, the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2021 estimated that all CGF (mild, moderate, and severe) was associated with 774 000 deaths and 70·2 million DALYs in children younger than 5 years in 2021. Despite the crucial importance of understanding the causes and relative risks of negative health outcomes associated with CGF, global estimates of the increased relative risks of negative health outcomes associated with CGF typically rely on a synthetic review of 11 studies that were conducted between 1977 and 1997.

### Added value of this study

Using updated estimates from GBD 2023 of both the relative risks of CGF associated with health outcomes as well as the proportion of children experiencing CGF, we present estimates of the global burden associated with CGF aggregated across mild, moderate, and severe forms for each of three CGF indicators: stunting (low height-for-age), underweight (low weight-for-age), and wasting (low weight-for-height). For each indicator, our estimates represent burden estimates for children that are at least 1 SD below the WHO Child Growth Standards. The length and quality of the studies included in the re-estimation of relative risks allowed for distinct quantification of the morbidity and mortality risk associated with each CGF indicator for lower respiratory infections, diarrhoea, measles, and malaria. In particular, using relative risks based on increased mortality alone, we found that more than 18% of all under-5 deaths were associated with CGF, with almost as many deaths associated with stunting as with wasting.

### Implications of all the available evidence

Previous estimates of CGF identified wasting as the primary CGF risk factor associated with disease burden. We found that stunting is associated with almost as much of the global CGF burden as wasting and that stunting prevalence has decreased at a far slower rate than wasting over the past decades. Given the previously observed difficulty in a child recovering from stunting after their third month of life, our estimates should serve as a call to refocus efforts to avert CGF at the earliest stages of onset.

disease burden on a global scale is of crucial importance for devising targeted interventions and policies aimed at alleviating its associated burden and generating advocacy for funding prevention and treatment.

Since 1990, substantial strides have been made in reducing childhood mortality and improving overall child growth and health,[7] despite some setbacks caused by disruptions in health-care services and treatment of acute malnutrition due to the COVID-19 pandemic.[8] However, many countries are not on track to meet the UN Sustainable Development Goals for reducing child mortality and the prevalence of CGF, and there is substantial overlap in the countries that have high child mortality and CGF.[7,9] In 2019, more than half of all under-5 deaths globally were attributable to malnutrition, including CGF, low birthweight and short gestation, suboptimal breastfeeding, vitamin A deficiency, and zinc deficiency.[2] This is in part because growth failure is a leading risk factor associated with primary infectious causes of death among children younger than 5 years.[3]

Numerous interventions exist that can prevent CGF, such as increased rates of exclusive breastfeeding[10] and improved micronutrient uptake,[11] but the effectiveness of these interventions varies across CGF indicators[11] as well as by the age of the child.[12] As outlined in the most recent WHO guidelines, severe acute malnutrition in children from 0 to 59 months of age can frequently be managed by community health workers and increased monitoring of the child's health.[13] Although community case management can also help reduce stunting, the likelihood of successfully reversing stunting decreases as the infant grows older,[14] indicating that identifying children whose growth is faltering as early as possible is critical. Substantial evidence suggests that short gestation, low birthweight, and factors influencing a fetus's development in utero drive many growth outcomes in the early years of life and that the ideal time to intervene on growth failure might be before the child is born[15] or even conceived.[16] Finally, although CGF is a risk factor associated with more severe outcomes for various infectious diseases, enteric infections can also alter intestinal absorption rates, increasing the likelihood of CGF and creating a so-called vicious cycle.[17] Improved integrated case management and immediate access to treatments such as oral rehydration solution can reduce the severity of disease and in turn decrease the likelihood of growth failure.[17] Proximal and effective interventions with strong evidence of impact are described in appendix 1 (table S7). A concerted effort by the global community to increase detection of CGF and access to treatment has led to substantial declines in CGF over the past few decades.

See Online for appendix 1

Many existing estimates of CGF focus primarily on the prevalence of moderate and severe stunting, underweight, and wasting, defined by the proportions of children less than two Z scores from the median age-specific and sex-specific global growth standards for height-for-age (HAZ) for stunting, weight-for-age (WAZ) for underweight, and weight-for-height (WHZ) for wasting.[4,18] Measuring the prevalence of these indicators is convenient for comparing populations between geographical regions and over time and for defining and

***Panel*: Rationale for modelling all child growth failure (mild, moderate, and severe)**

We modelled all child growth failure (mild, moderate, and severe) at height-for-age Z scores (HAZ), weight-for-age Z scores (WAZ), and weight-for-height Z scores (WHZ) less than –1 to capture a broader distribution of risk than the conventional Z score less than –2 threshold. Evidence suggests that the risks of infectious morbidity and mortality increase even with mild growth deficits (Z score <–1), and continuous risk curves allow more accurate estimation of the attributable burden. This approach aligns with Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) methodology, which emphasises modelling the full distribution of exposure rather than categorical cut-offs.

For the **GBD 2023 Sources Tool** see https://ghdx.healthdata.org/gbd-2023/sources

monitoring progress towards global goals.[19] However, focusing exclusively on these prevalence estimates might obscure meaningful changes in population distributions and does not connect CGF with disease burden and mortality.[20]

This analysis extends on previous estimates of the prevalence of CGF by including all forms of CGF (mild, moderate, and severe; panel), quantifying infectious-disease-specific attributable fractions from previously estimated continuous distributions of growth indicators and newly estimated continuous relative risks for incidence and mortality due to diarrhoea, lower respiratory infections, measles, and malaria.[4,18,20] In this study, based on the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2023, we present comprehensive estimates of disability-adjusted life-years (DALYs) and deaths associated with CGF at the global, regional, and national level, including changes over time. Additionally, we describe updated cause-specific risks of incidence and mortality associated with each CGF indicator and the associated attributable burden. The resulting estimates of the disease burden associated with CGF are available for 204 countries and territories, five age groups younger than 5 years, by sex, from 1990 to 2023. This manuscript was produced as part of the GBD Collaborator Network and in accordance with the GBD Protocol.[21]

## Methods

### Overview

We used four main methodological steps to estimate the burden of all CGF (mild, moderate, and severe). To estimate the attributable fractions for each of the three risk factor components of CGF modelled in GBD—stunting, underweight, and wasting—for diarrhoea, lower respiratory infections, malaria, and measles, we produced estimates of exposure and estimates of the risk of disease given varying levels of exposure. Finally, we multiplied those attributable fractions by cause-specific cases, deaths, and DALYs to produce our results for CGF burden. Each step is described briefly here with specific references for further information. The analyses in this study follow the methods published by the GBD 2023 Disease and Injury and Risk Factor Collaborators.[22] They have been described in full elsewhere[22] and are summarised below.

### Estimation of the population-level distributions of HAZ, WAZ, and WHZ

A detailed description of the methods used to estimate continuous distributions for each of the CGF indicators is provided in the study by Fitzgerald and colleagues.[20] We included data from various sources, such as population-representative surveys, administrative data, and published scientific literature. More than 1700 sources were used in this model; citations and metadata for all sources used in the analysis are available for download from the GBD 2023 Sources Tool. A spatiotemporal Gaussian process regression (ST-GPR) model, a methodology used across many models in GBD that leverages evidence across time and space to produce estimates for each indicator, age group, sex, year, and location, was used to make predictions of the mean HAZ, WAZ, and WHZ and the prevalence of moderate (<–2 Z scores) and severe (<–3 Z scores) growth failure by age, sex, year, and location. This model includes linear effects on maternal care and immunisation, Healthcare Access and Quality (HAQ) Index, prevalence of severe anaemia, the Socio-demographic Index (SDI), age-specific and sex-specific unsafe sanitation summary exposure value, and all-age energy (kilocalories per person per day) as covariates.

Separately, we fit an ensemble model of distribution families to describe each CGF Z score distribution from individual-level data. Ten distributions were fit simultaneously (normal, log-normal, log-logistic, exponential, gamma, mirrored gamma, inverse gamma, Gumbel, mirrored Gumbel, and Weibull). We derived weights for each distribution based on minimised error in predicting CGF prevalence of less than –1 Z score, less than –2 Z scores, and less than –3 Z scores. Finally, we synthesised the results from these steps to estimate continuous HAZ, WAZ, and WHZ curves to estimate a weighted probability density function based on the ensemble distributions and ST-GPR mean and SD values.

### Estimation of the relative risk of cause-specific incidence and mortality at varying levels of CGF indicators

We created new estimates of the relative risk of cause-specific incidence and mortality for continuous distributions of CGF exposure for GBD 2021 and used these estimates for GBD 2023. Estimates of CGF burden in previous GBD publications used categorical exposures (–3, –2, and –1 Z scores) matched with relative risks of cause-specific disease burden at each of those levels of exposure.[22,23] A longer description of the methods is available elsewhere,[22] and we have summarised the methods below.

For cause-specific mortality, we included 22 870 children and more than 137 000 anthropometric measurements from eight studies, representing 1029 cause-specific deaths (283 due to diarrhoea, 737 due to acute lower respiratory infections, and nine due to malaria). We also included hazard ratios for cause-specific mortality from a pooled analysis by Olofin and colleagues[3] in our meta-regression. For cause-specific incidence, we included 60 436 children and more than 286 000 anthropometric measurements from 19 studies, representing more than 100 000 unique study-defined infectious disease episodes (95 950 diarrhoea episodes, 12 947 acute lower respiratory infections, 4896 malaria episodes, and 376 measles episodes). These data were from longitudinal studies that reported multiple measurements of height and bodyweight over time. We collapsed these observations into bins of Z scores for each CGF indicator and by age and study while summing the number of child-days of infectious disease episodes based on a standardised one-week recall, and cause-specific deaths within each bin.

We used a Bayesian meta-regression tool and risk factor assessment framework built for GBD and used across risk factors to quantify a continuous risk curve for each CGF exposure category and outcome.[24] Each risk exposure indicator (HAZ, WAZ, and WHZ) across the Z score range –6 to 1 was paired with each outcome (incidence and mortality for each infectious disease) to create a risk–outcome pair. In other words, we built separate models for the incidence and mortality rates for each infectious disease outcome, and for each metric of growth failure (24 models). We used logit-transformed mortality ratio and log-transformed incidence as the continuous independent variables in our models. Age was included as a fixed effect in the model. Studies were included as random intercepts in the model, and a flexible regularised spline fitting algorithm determined the shape of the curves. Age was chosen as a fixed effect since we wished to estimate the specific impact of age on the outcomes while our random effects were chosen as such due to our interest in estimating both the differences by study as well as the general variation one would expect from study to study. The meta-regression model incorporates both within-study and between-study uncertainty measured by standard errors and simulates Bayesian uncertainty intervals including and excluding between-study variation. More details on the meta-regression tool can be found in the publication associated with the method[24] as well as the publication from which the relative risk estimates are taken.[23]

Because of the high degree of correlation between stunting, underweight, and wasting, we adjusted our relative risk values by simulating a joint distribution of the three indicators using extracted data from Demographic and Health Surveys. Based on an analysis done by McDonald and colleagues,[5] we fit an interaction term between the three indicators and calculated adjusted relative risks by minimising the error between the crude relative risks from our meta-regression and the expected relative risk derived from the joint estimate with the interaction term. More details of the specific approach taken are provided in appendix 1 of the report by the GBD 2023 Disease and Injury and Risk Factor Collaborators.[22]

### Calculation of a cause-age-sex-location-specific attributable fraction and multiplication by cause burden

Given that there were two continuous distributions, we produced estimates of the attributable fraction of disease incidence and mortality. The attributable fraction represents the proportion of disease burden that was attributable to a given risk factor (ie, the proportion of disease burden that would not exist in the absence of the risk factor). As CGF does not directly cause infections or deaths, the interpretation of the percentage attributable fraction is the proportion of disease burden that would not exist in the absence of the risk factor due to the linked reduction in associated direct biological drivers that cause increased burden such as immune system dysregulation.

The attributable fraction for continuous population-level exposure estimates and relative risks is:

$$PAF_{i,m,c}=\frac{\int_0^\infty RR_{i,m,c}(x)P_i(x)dx-1}{\int_0^\infty RR_{i,m,c}(x)P_i(x)dx}$$

where $i$ is the CGF indicator (HAZ, WAZ, or WHZ), $m$ is the disease outcome (incidence or death), and $c$ is the cause (diarrhoea, lower respiratory infections, malaria, or measles). An attributable fraction for CGF overall was estimated with a multiplicative aggregation of the individual indicator attributable fractions:

$$PAF_{m,c}=1-\prod_{i-1}^{n}(1-PAF_{i,m,c})$$

Notably, due to a scarcity of data, GBD does not estimate attributable burden for stunting in the early neonatal (0–6 days) and late neonatal (7–27 days) age groups. Attribution is estimated for the following age groups: 1 to less than 6 months, 6 to less than 12 months, 12 to less than 24 months, 24 to less than 60 months.

### Cause-specific incidence and mortality modelling

A full description of the modelling methods for the incidence and mortality of diarrhoea, lower respiratory infections, malaria, and measles has been published previously.[25,26]

In short, mortality due to diarrhoea, lower respiratory infections, and measles was modelled with a Bayesian ensemble hierarchical tool called the Cause of Death Ensemble model (CODEm).[27] Measles used CODEm for settings with vital registration systems and used a separate model based on incidence and case-fatality ratio

for other settings.[27] Malaria mortality was modelled with spatially defined incidence and case-fatality estimates.[27,28] Input data included vital registration, verbal autopsy, administrative records, and surveys. Covariates informed the models, and the final set of ensemble models was selected on the basis of out-of-sample predictive validity. Non-fatal incidence of diarrhoea and lower respiratory infections was modelled in a meta-regression tool with data from population-representative surveys, clinical data, administrative data, and scientific literature.[27] This meta-regression tool includes a compartmental component that enforces consistency between disease incidence and mortality, making it an internally consistent estimate with mortality. Malaria incidence was based on estimates from the Malaria Atlas Project and on administrative, routine surveillance, and other geolocated and community-representative observations of infection prevalence for *Plasmodium falciparum*.[28] Measles incidence was estimated in a mixed-effects regression model by use of Joint Reporting Form case notifications and 5-year rolling lagged routine measles vaccination rates.[27]

| | Child growth failure | Child underweight | Child wasting | Child stunting |
|---|---|---|---|---|
| **Global** | | | | |
| All causes | 79 400 000 (47 000 000 to 106 000 000) | 52 200 000 (21 900 000 to 75 100 000) | 39 200 000 (23 800 000 to 53 000 000) | 33 000 000 (24 100 000 to 42 200 000) |
| Diarrhoeal diseases | 21 800 000 (13 000 000 to 32 200 000) | 10 600 000 (5 870 000 to 17 400 000) | 15 100 000 (–1 090 000 to 29 200 000) | 7 580 000 (4 290 000 to 11 700 000) |
| Lower respiratory infections | 32 100 000 (22 400 000 to 41 200 000) | 22 100 000 (1 690 000 to 38 000 000) | 12 500 000 (7 900 000 to 18 100 000) | 17 300 000 (12 200 000 to 23 400 000) |
| Malaria | 9 600 000 (–6 360 000 to 30 400 000) | 6 980 000 (–4 070 000 to 20 500 000) | .. | 4 460 000 (–2 350 000 to 19 700 000) |
| Measles | 6 930 000 (2 700 000 to 13 300 000) | 3 560 000 (1 330 000 to 6 880 000) | 2 590 000 (782 000 to 5 530 000) | 3 690 000 (1 320 000 to 7 100 000) |
| **Central Europe, eastern Europe, and central Asia** | | | | |
| All causes | 792 000 (577 000 to 1 030 000) | 442 000 (54 500 to 876 000) | 314 000 (246 000 to 393 000) | 303 000 (198 000 to 406 000) |
| Diarrhoeal diseases | 70 500 (32 900 to 105 000) | 22 000 (12 500 to 34 800) | 51 000 (–2120 to 97 000) | 17 900 (11 800 to 25 600) |
| Lower respiratory infections | 706 000 (526 000 to 920 000) | 405 000 (15 000 to 841 000) | 248 000 (158 000 to 342 000) | 285 000 (184 000 to 385 000) |
| Malaria | 0 (0 to 0) | 0 (0 to 0) | .. | 0 (0 to 0) |
| Measles | 1040 (501 to 1450) | 351 (163 to 510) | 374 (140 to 751) | 510 (233 to 737) |
| **High income** | | | | |
| All causes | 57 900 (37 100 to 92 300) | 30 100 (9950 to 64 800) | 24 800 (18 200 to 32 900) | 17 700 (13 900 to 23 500) |
| Diarrhoeal diseases | 11 500 (2420 to 23 200) | 2750 (1840 to 4370) | 7450 (–436 to 19 100) | 2450 (1130 to 3840) |
| Lower respiratory infections | 38 800 (26 600 to 64 000) | 19 800 (514 to 54 600) | 9830 (5620 to 14 400) | 15 200 (10 900 to 21 100) |
| Malaria | 0·0753 (–0·0302 to 0·312) | 0·0753 (–0·0302 to 0·312) | .. | <0·001 (>–0·001 to <0·001) |
| Measles | 4·48 (1·66 to 6·86) | 1·25 (0·478 to 2·01) | 1·77 (0·561 to 3·58) | 1·73 (0·654 to 2·83) |
| **Latin America and Caribbean** | | | | |
| All causes | 1 470 000 (1 110 000 to 1 850 000) | 920 000 (427 000 to 1 430 000) | 624 000 (450 000 to 788 000) | 566 000 (417 000 to 728 000) |
| Diarrhoeal diseases | 322 000 (202 000 to 460 000) | 118 000 (67 800 to 188 000) | 183 000 (–6980 to 415 000) | 115 000 (76 600 to 159 000) |
| Lower respiratory infections | 878 000 (641 000 to 1 180 000) | 528 000 (22 700 to 1 070 000) | 168 000 (97 600 to 242 000) | 451 000 (318 000 to 578 000) |
| Malaria | 1810 (–892 to 6850) | 1320 (–665 to 4290) | .. | 684 (–239 to 3520) |
| Measles | 3·5 (1·53 to 5·11) | 1·09 (0·494 to 1·64) | 0·849 (0·322 to 1·76) | 1·95 (0·797 to 2·86) |
| **North Africa and Middle East** | | | | |
| All causes | 2 800 000 (2 020 000 to 3 590 000) | 1 790 000 (884 000 to 2 690 000) | 1 490 000 (1 070 000 to 1 920 000) | 1 120 000 (816 000 to 1 470 000) |
| Diarrhoeal diseases | 582 000 (284 000 to 1 010 000) | 254 000 (128 000 to 458 000) | 403 000 (–20 700 to 873 000) | 203 000 (107 000 to 345 000) |
| Lower respiratory infections | 1 480 000 (1 010 000 to 2 050 000) | 947 000 (61 500 to 1 830 000) | 565 000 (328 000 to 848 000) | 749 000 (486 000 to 1 060 000) |
| Malaria | 43 800 (–33 200 to 126 000) | 34 500 (–23 800 to 98 100) | .. | 17 600 (–7240 to 72 500) |
| Measles | 282 000 (99 700 to 585 000) | 138 000 (50 100 to 288 000) | 103 000 (33 100 to 217 000) | 154 000 (50 100 to 321 000) |
| **South Asia** | | | | |
| All causes | 15 400 000 (12 500 000 to 18 100 000) | 10 800 000 (5 050 000 to 14 600 000) | 9 500 000 (7 040 000 to 11 500 000) | 6 210 000 (4 460 000 to 8 120 000) |
| Diarrhoeal diseases | 4 020 000 (2 660 000 to 5 630 000) | 2 180 000 (1 400 000 to 3 290 000) | 2 930 000 (–263 000 to 5 150 000) | 1 390 000 (875 000 to 2 060 000) |
| Lower respiratory infections | 8 790 000 (6 880 000 to 10 700 000) | 6 310 000 (526 000 to 9 610 000) | 4 430 000 (3 020 000 to 6 100 000) | 4 430 000 (2 850 000 to 6 110 000) |
| Malaria | 179 000 (–145 000 to 598 000) | 140 000 (–97 700 to 450 000) | .. | 76 400 (–37 100 to 360 000) |
| Measles | 602 000 (231 000 to 1 270 000) | 336 000 (119 000 to 717 000) | 285 000 (84 700 to 623 000) | 305 000 (111 000 to 653 000) |

(Table 1 continues on next page)

| | Child growth failure | Child underweight | Child wasting | Child stunting |
|---|---|---|---|---|
| (Continued from previous page) | | | | |
| **Southeast Asia, east Asia, and Oceania** | | | | |
| All causes | 3 730 000 (2 810 000 to 4 660 000) | 2 380 000 (1 020 000 to 3 520 000) | 1 840 000 (1 320 000 to 2 370 000) | 1 520 000 (1 110 000 to 1 990 000) |
| Diarrhoeal diseases | 924 000 (472 000 to 1 530 000) | 417 000 (208 000 to 751 000) | 611 000 (–33 600 to 1 340 000) | 322 000 (168 000 to 552 000) |
| Lower respiratory infections | 2 130 000 (1 500 000 to 2 800 000) | 1 430 000 (96 800 to 2 580 000) | 737 000 (439 000 to 1 070 000) | 1 060 000 (703 000 to 1 480 000) |
| Malaria | 12 700 (–8810 to 44 300) | 9450 (–5840 to 30 700) | .. | 5450 (–2700 to 26 400) |
| Measles | 246 000 (91 200 to 486 000) | 118 000 (41 700 to 245 000) | 82 000 (24 600 to 172 000) | 133 000 (49 500 to 273 000) |
| **Sub-Saharan Africa** | | | | |
| All causes | 55 200 000 (26 700 000 to 77 100 000) | 35 800 000 (13 400 000 to 53 100 000) | 25 400 000 (14 400 000 to 36 800 000) | 23 300 000 (14 600 000 to 34 000 000) |
| Diarrhoeal diseases | 15 900 000 (9 100 000 to 24 400 000) | 7 600 000 (4 100 000 to 12 600 000) | 10 900 000 (–762 000 to 21 600 000) | 5 530 000 (2 950 000 to 8 790 000) |
| Lower respiratory infections | 18 100 000 (11 100 000 to 25 400 000) | 12 400 000 (969 000 to 22 400 000) | 6 360 000 (3 670 000 to 10 200 000) | 10 300 000 (6 660 000 to 14 400 000) |
| Malaria | 9 360 000 (–6 160 000 to 29 600 000) | 6 790 000 (–3 940 000 to 20 000 000) | .. | 4 360 000 (–2 290 000 to 19 200 000) |
| Measles | 5 800 000 (2 210 000 to 11 100 000) | 2 960 000 (1 090 000 to 5 690 000) | 2 120 000 (628 000 to 4 460 000) | 3 100 000 (1 070 000 to 6 070 000) |

Estimates combine the burden associated with mild, moderate, and severe forms of child growth failure: stunting was defined as height-for-age Z score (HAZ) less than –1; underweight was defined as weight-for-age Z score (WAZ) less than –1; and wasting was defined as weight-for-height Z score (WHZ) less than –1, according to WHO Child Growth Standards. The meta-regression model used to estimate relative risks for various levels of risk-factor exposure incorporates both within-study and between-study uncertainty measured by standard errors. The results presented herein incorporate between-study variation, meaning the uncertainty intervals here represent both uncertainty in the relative risks as well as predicted variation due to between-study variation, and as such some uncertainty intervals' lower bounds fall below zero. As described in the publication associated with the method,[24] a risk factor, outcome, or cause combination would not be included in the table if the uncertainty without between-study variation was not statistically significantly different from zero. Data in parentheses are 95% uncertainty intervals. Count data are presented to three significant figures. GBD=Global Burden of Diseases, Injuries, and Risk Factors Study.

***Table 1:*** **All-cause and cause-specific DALYs associated with child growth failure among children younger than 5 years at the global and GBD super-regional levels, 2023**

Cause-specific cases and deaths were multiplied by the population attributable fraction (PAF) values to produce our final estimates of the disease burden associated with each CGF indicator. All steps in the estimation process included 500 iterations of each age-sex-geography-year-specific value. 95% uncertainty intervals (UIs) were calculated as the 2·5th and 97·5th percentiles across all draws. This uncertainty was carried through the entire process to maintain the variation in the estimates. Count data are presented to three significant figures, while rates and percentages are presented to one decimal place.

The code and input data are available on the Global Health Data Exchange (GHDx) website. This study complies with the GATHER requirements for burden estimation and reporting.[29]

### Role of the funding source

The funder of this study had no role in study design, data collection, data analysis, data interpretation, or the writing of the report.

## Results

Globally, in 2023, in children younger than 5 years, all CGF (mild, moderate, and severe) was associated with 79·4 million (95% UI 47·0–106) DALYs, ranking only behind low birthweight and short gestation (133 million [125–143] DALYs) as the leading risk factors associated with health burden among all children younger than 5 years (table 1; appendix 1 table S1). CGF was associated with 17·9% (10·6–23·8) of 444 million (434–457) total under-5 DALYs (table 2; appendix table S2). In 2023, CGF was associated with 880 000 (517 000–1 170 000) deaths (figures 1, 2; table 3; appendix 1 table S3), representing 18·8% (11·1–25·0) of all 4·67 million (4·59–4·75) under-5 deaths (figure 1; table 4; appendix 1 table S4) and 1·54 million (0·804–2·41) years lived with disability (YLDs; appendix 1 table S5), representing 5·5% (3·2–7·9) of all 28·0 million (20·4–37·1) under-5 YLDs (figure 2; appendix 1 table S6). Due to limited space and similar trends between DALYs and mortality through time and across countries by indicator and cause, we primarily focus the results presented below on mortality. Full estimates produced in association with these analyses across all health metrics are available via the GBD Results Tool.

The number of deaths associated with CGF was 2·75 million (95% UI 1·95–3·27) in 2000, decreasing by an average of 5·0% (4·2–5·9) per year to 880 000 (517 000–1 170 000) in 2023 (figure 1; GBD Results Tool). Some of these decreases were due to secular trends in disease burden not related to CGF. The attributable fraction of CGF decreased at a slower rate, by 2·1% (1·4–3·0) per year since 2000, from 30·5% (21·5–36·3) of deaths in children younger than 5 years in 2000 to 18·8% (11·1–25·0) in 2023 (figure 1; table 4). However, the attributable fraction of CGF among all causes of death for which it contributes as a risk factor decreased less rapidly between 2000, from 73·7% (53·9–86·3) in 2000 to 61·2% (33·6–79·2) in 2023, representing a 0·9% (0·3–2·0) average yearly reduction (GBD Results Tool).[22]

Among the different indicators of CGF, underweight was associated with the greatest disease burden:

For the **code and input data** see https://ghdx.healthdata.org/gbd-2023/code

For the **GBD Results Tool** see https://vizhub.healthdata.org/gbd-results/

12·3% (95% UI 5·1–17·6) of all deaths in children younger than 5 years in 2023, followed by child wasting (9·2% [5·5–12·5]) and child stunting (8·0% [6·0–10·3]; figure 1, table 4; appendix 1 table S4). The fastest decline in attributable burden from 2000 was in child stunting (2·6% [1·8–3·6] decline per year), followed by child wasting (2·4% [1·5–3·2] decline per year) and underweight (2·3% [1·5–3·2] decline per year; figure 1).

In 2023, at the GBD super-regional level, the highest percentage of total under-5 deaths associated with CGF occurred in sub-Saharan Africa (23·4% [95% UI 11·3 to 32·8]) and in south Asia (14·6% [11·8 to 16·8]; table 4; appendix 1 table S4). In 2023, CGF was associated with 618 000 (299 000 to 862 000) deaths in sub-Saharan Africa and 165 000 (134 000 to 194 000) deaths in south Asia (table 3, appendix 1 table S3). At the national level, in 2023, the largest numbers

| | Child growth failure | Child underweight | Child wasting | Child stunting |
|---|---|---|---|---|
| **Global** | | | | |
| All causes | 17·9% (10·6 to 23·8) | 11·7% (5·0 to 16·8) | 8·8% (5·4 to 11·9) | 7·4% (5·6 to 9·5) |
| Diarrhoeal diseases | 75·2% (53·1 to 88·1) | 36·6% (24·9 to 47·3) | 51·9% (–3·1 to 84·2) | 26·2% (18·6 to 31·9) |
| Lower respiratory infections | 59·1% (48·5 to 66·5) | 40·5% (2·7 to 63·0) | 23·0% (16·0 to 29·3) | 31·8% (24·3 to 37·9) |
| Malaria | 26·3% (–17·8 to 69·4) | 19·1% (–11·6 to 48·9) | .. | 12·1% (–6·2 to 44·7) |
| Measles | 66·4% (39·9 to 75·8) | 34·0% (18·3 to 42·4) | 24·9% (10·8 to 40·9) | 35·3% (17·3 to 43·5) |
| **Central Europe, eastern Europe, and central Asia** | | | | |
| All causes | 11·2% (8·2 to 14·7) | 6·2% (0·76 to 12·6) | 4·4% (3·5 to 5·5) | 4·3% (2·8 to 5·7) |
| Diarrhoeal diseases | 56·4% (27·8 to 78·1) | 17·7% (10·5 to 24·7) | 40·7% (–1·8 to 74·2) | 14·4% (10·0 to 18·3) |
| Lower respiratory infections | 43·5% (32·8 to 57·2) | 24·9% (0·93 to 52·3) | 15·3% (10·0 to 20·4) | 17·5% (11·4 to 23·5) |
| Malaria | 0% (0 to 0) | 0% (0 to 0) | .. | 0% (0 to 0) |
| Measles | 38·9% (18·9 to 48·4) | 13·1% (6·2 to 17·5) | 14·0% (5·3 to 25·6) | 19·0% (8·7 to 25·4) |
| **High income** | | | | |
| All causes | 0·98% (0·62 to 1·6) | 0·51% (0·17 to 1·1) | 0·42% (0·30 to 0·57) | 0·30% (0·23 to 0·41) |
| Diarrhoeal diseases | 18·4% (3·9 to 35·5) | 4·4% (2·8 to 6·9) | 11·9% (–0·69 to 29·1) | 3·9% (1·7 to 6·1) |
| Lower respiratory infections | 34·6% (24·4 to 54·5) | 17·6% (0·44 to 47·2) | 8·8% (5·1 to 12·2) | 13·6% (9·9 to 17·7) |
| Malaria | 8·3% (–3·4 to 29·8) | 8·3% (–3·4 to 29·8) | .. | <0·1% (>–0·1 to <0·1) |
| Measles | 13·6% (6·0 to 17·7) | 3·8% (1·8 to 5·2) | 5·4% (1·9 to 10·0) | 5·2% (2·4 to 7·2) |
| **Latin America and Caribbean** | | | | |
| All causes | 9·2% (6·9 to 11·6) | 5·8% (2·7 to 9·1) | 3·9% (2·8 to 5·0) | 3·5% (2·6 to 4·5) |
| Diarrhoeal diseases | 55·0% (36·4 to 73·7) | 20·2% (12·1 to 28·7) | 31·3% (–1·1 to 66·5) | 19·6% (13·7 to 24·7) |
| Lower respiratory infections | 52·2% (38·7 to 68·7) | 31·3% (1·3 to 63·2) | 10·0% (6·0 to 13·6) | 26·8% (18·7 to 33·5) |
| Malaria | 14·5% (–7·2 to 45·5) | 10·8% (–5·3 to 31·2) | .. | 5·1% (–2·2 to 23·4) |
| Measles | 25·7% (12·3 to 32·4) | 8·0% (3·8 to 10·6) | 6·2% (2·4 to 11·7) | 14·3% (6·5 to 19·7) |
| **North Africa and Middle East** | | | | |
| All causes | 10·1% (7·3 to 12·8) | 6·5% (3·2 to 9·6) | 5·4% (3·9 to 6·9) | 4·1% (3·0 to 5·3) |
| Diarrhoeal diseases | 64·7% (39·9 to 80·9) | 28·2% (19·2 to 37·9) | 44·7% (–2·1 to 77·1) | 22·5% (16·2 to 27·9) |
| Lower respiratory infections | 54·0% (43·8 to 63·1) | 34·5% (2·0 to 58·7) | 20·7% (13·9 to 27·0) | 27·5% (18·9 to 34·8) |
| Malaria | 31·3% (–23·3 to 78·1) | 24·7% (–17·2 to 60·2) | .. | 12·3% (–6·3 to 49·0) |
| Measles | 61·1% (34·4 to 70·9) | 29·8% (15·1 to 38·1) | 22·4% (9·3 to 38·7) | 33·3% (15·5 to 41·2) |
| **South Asia** | | | | |
| All causes | 14·1% (11·4 to 16·3) | 9·9% (4·6 to 12·8) | 8·7% (6·4 to 10·2) | 5·7% (4·1 to 7·3) |
| Diarrhoeal diseases | 77·1% (55·2 to 86·8) | 41·8% (30·2 to 51·9) | 56·2% (–3·9 to 83·6) | 26·7% (19·0 to 32·4) |
| Lower respiratory infections | 53·1% (45·1 to 58·8) | 38·2% (2·9 to 55·9) | 26·8% (19·4 to 33·3) | 26·8% (17·3 to 33·8) |
| Malaria | 32·1% (–24·4 to 78·9) | 25·2% (–17·7 to 60·4) | .. | 13·4% (–7·2 to 50·9) |
| Measles | 75·2% (48·7 to 84·8) | 42·0% (23·7 to 51·0) | 35·8% (16·4 to 55·2) | 38·0% (19·0 to 46·4) |
| **Southeast Asia, east Asia, and Oceania** | | | | |
| All causes | 11·2% (8·4 to 13·7) | 7·1% (3·0 to 10·4) | 5·5% (4·0 to 7·1) | 4·6% (3·4 to 5·9) |
| Diarrhoeal diseases | 68·5% (44·7 to 83·9) | 31·0% (21·3 to 40·3) | 45·1% (–2·3 to 78·0) | 23·8% (17·2 to 29·2) |
| Lower respiratory infections | 56·5% (43·5 to 66·0) | 37·8% (2·2 to 62·6) | 19·5% (13·0 to 25·3) | 28·0% (19·3 to 34·9) |
| Malaria | 26·1% (–18·5 to 69·2) | 19·6% (–12·5 to 51·3) | .. | 10·6% (–5·5 to 42·1) |
| Measles | 60·9% (35·4 to 70·2) | 29·3% (15·6 to 36·7) | 20·5% (8·5 to 35·1) | 32·9% (16·3 to 40·7) |

(Table 2 continues on next page)

| | Child growth failure | Child underweight | Child wasting | Child stunting |
|---|---|---|---|---|
| (Continued from previous page) | | | | |
| **Sub-Saharan Africa** | | | | |
| All causes | 22·5% (10·9 to 31·7) | 14·6% (5·5 to 21·7) | 10·4% (5·9 to 15·0) | 9·5% (6·0 to 13·9) |
| Diarrhoeal diseases | 76·5% (54·2 to 89·5) | 36·6% (24·5 to 47·9) | 52·4% (–3·0 to 86·0) | 26·6% (18·9 to 32·7) |
| Lower respiratory infections | 64·8% (52·2 to 73·6) | 44·4% (2·9 to 69·3) | 22·8% (15·1 to 30·0) | 36·9% (30·2 to 42·9) |
| Malaria | 26·2% (–17·7 to 69·3) | 19·0% (–11·5 to 48·7) | .. | 12·1% (–6·2 to 44·6) |
| Measles | 66·1% (39·4 to 75·7) | 33·8% (18·1 to 42·1) | 24·3% (10·4 to 40·2) | 35·3% (17·3 to 43·6) |

Estimates combine the burden associated with mild, moderate, and severe forms of child growth failure: stunting was defined as height-for-age Z score (HAZ) less than –1; underweight was defined as weight-for-age Z score (WAZ) less than –1; and wasting was defined as weight-for-height Z score (WHZ) less than –1, according to WHO Child Growth Standards. The results presented herein incorporate between-study variation, meaning the uncertainty intervals here represent both uncertainty in the relative risks as well as predicted variation due to between-study variation, and as such some uncertainty intervals' lower bounds fall below zero. As described in the publication associated with the method,[24] a risk factor, outcome, or cause combination would not be included in the table if the uncertainty without between-study variation was not statistically significantly different from zero. Data in parentheses are 95% uncertainty intervals. Population attributable fractions are presented to one decimal place. DALY=disability-adjusted life-year. GBD=Global Burden of Diseases, Injuries, and Risk Factors Study.

***Table 2:*** **All-cause and cause-specific population attributable fraction of DALYs among children younger than 5 years for child growth failure at the global and GBD super-regional levels, 2023**

of deaths among children younger than 5 years associated with CGF occurred in Nigeria (188 000 [70 200 to 270 000]), India (112 000 [88 300 to 131 000]), and DR Congo (50 800 [17 000 to 87 800]; appendix 1 table S3). The highest proportions of under-5 deaths associated with CGF in 2023 were in Chad (40·2% [27·9 to 48·8] of all under-5 deaths), Niger (34·9% [17·3 to 45·5]), and South Sudan (32·8% [18·9 to 43·3]; appendix 1 table S4). Globally, in 2023, CGF was associated with 362 000 (253 000 to 465 000) deaths due to lower respiratory infections in children younger than 5 years (59·4% [48·9 to 66·8] of 610 000 [486 000 to 749 000] deaths due to lower respiratory infection in children <5 years), followed by diarrhoeal diseases (243 000 [146 000 to 360 000]; 76·7% [54·9 to 89·1] of 317 000 [213 000 to 462 000] under-5 diarrhoea deaths), malaria (107 000 [–71 300 to 341 000]; 26·4% [–17·8 to 69·5] of 409 000 [158 000 to 735 000] under-5 malaria deaths), and measles (78 600 [30 700 to 150 000] deaths; 66·6% [40·0 to 76·0] of 118 000 [47 700 to 211 000] under-5 measles deaths; tables 3, 4; appendix 1 figures S1–S5; tables S3, S4). CGF was also associated with the burden of cause-specific infectious disease incidence, including 27·7% (–24·4 to 70·7) of 605 000 (387 000 to 884 000) under-5 malaria YLDs, 24·7% (–18·1 to 56·9) of 767 000 (527 000 to 1 070 000) under-5 diarrhoeal YLDs, 13·4% (–32·7 to 50·4) of 60 000 (40 100 to 85 900) under-5 lower respiratory infection YLDs, and 11·7% (–4·9 to 30·3) of 38 400 (15 000 to 80 000) under-5 measles YLDs (appendix 1 figures S1–S4, table S6). The CGF-attributable burden by cause varied substantially between countries and regions (figure 3; appendix 1 figure S5). The attributable fraction by cause was lowest among countries in the high-income super-region, but the range of deaths due to diarrhoea and lower respiratory infection associated with CGF still varied from 6·0% to 51·2% between countries in this super-region (appendix 1 table S2).

## Discussion

In 2023, CGF was a leading factor associated with mortality in children younger than 5 years globally, falling only behind short gestation and low birthweight, and was associated with approximately 791 000 deaths due to diarrhoea, lower respiratory infections, malaria, and measles. The burden associated with CGF decreased between 2000 and 2023 and has been an important correlate for tracking reductions in childhood mortality.[30,31] Multifaceted strategies are needed to address the intersectional contribution of environmental, socioeconomic, biological, and behavioural factors that affect childhood growth.

No single intervention is likely to improve childhood growth for all children.[1] Recent reviews of effective interventions for maternal and childhood malnutrition describe interventions (appendix 1 table S7) according to direct and indirect relationships between the health sector or other macro-level sectors and undernutrition and provide a useful framework to consider different interventions at different points in the life cycle.[32,33] Although societal and indirect interventions, such as family planning and reproductive health services, or poverty alleviation and women's empowerment strategies, might have important effects on CGF, several reviews have focused on the more proximal interventions that affect childhood environment and biology.[32,34]

Across the CGF indicators, childhood underweight was associated with the largest proportion of the under-5 disease burden. Due to the calculations for underweight, wasting, and stunting, WAZ scores are depressed by both wasting and stunting, making WAZ lowest when both substantial wasting and stunting are present. Moreover, there is evidence that wasting and stunting reinforce each other, meaning that stunting increases the risk of future wasting and vice versa—a relationship that gets stronger as a child grows older.[12] As such, locations with a high estimated burden

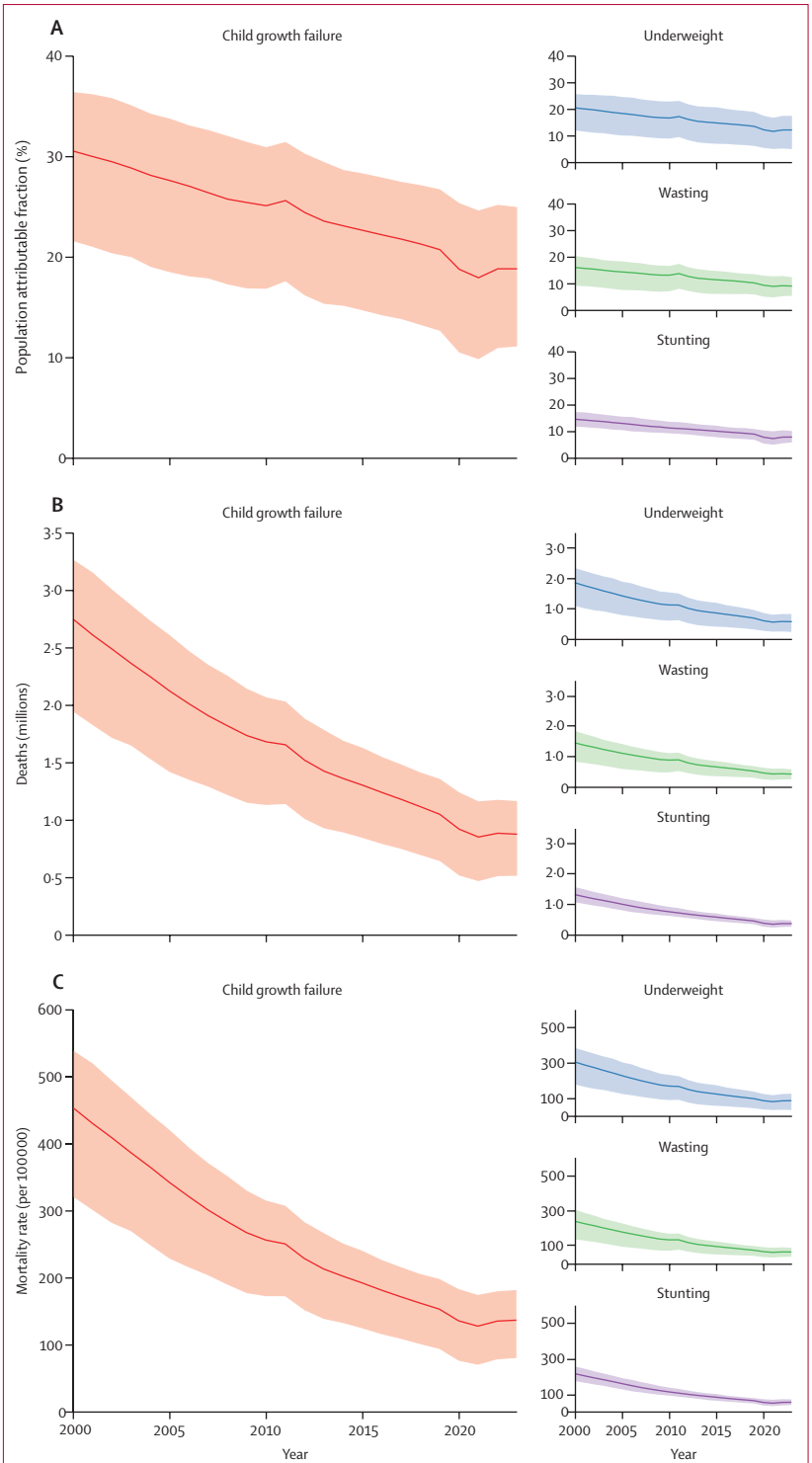


***Figure 1:*** **Global burden associated with child growth failure for children younger than 5 years as a fraction of all deaths (A), number of attributable deaths (B), and attributable mortality rate per 100 000 (C)**
Separate panels show the attributable burden for underweight, wasting, and stunting separately, as well as child growth failure as a whole. Shaded regions represent 95% uncertainty intervals. Estimates combine burden associated with mild, moderate, and severe forms of child growth failure: stunting was defined as height-for-age Z score (HAZ) less than –1; underweight was defined as weight-for-age Z score (WAZ) less than –1; and wasting was defined as weight-for-height Z score (WHZ) less than –1, according to WHO Child Growth Standards.

associated with all three CGF indicators are likely to require disproportionately more intense interventions than those where stunting and wasting are reinforcing each other.

Recovery from stunting is rare: most children who experience stunting do not recover towards the global mean for length or height, and those who do gain a small amount on their peers.[35] Although there is some evidence that stunting can be addressed after the first 1000 days of life,[36] early detection and intervention are critical for successful reversal of stunting.[4] Our work found that a larger proportion of the CGF burden was associated with stunting than in previous estimates; given the difficulty in reversing stunting, our estimates should be used to identify locations in need of increased early detection and intervention. In a pooled analysis by Mertens and colleagues,[12] comprising 19 studies and about 60 000 infants, the cumulative incidence, including at birth, of stunting was 25% in the first 3 months of life.[12] This study also found that the incidence of wasting peaked in the first 3 months of life.[12] Recovery from wasting is more common than from stunting. In the pooled analysis,[12] about 65% of infants recovered from wasting within 60 days in the first 3 months of life, and about 50% of infants who experienced wasting at older ages recovered in 60 days. This suggests that changes in lifestyle or interventions have a larger impact in younger compared to older children and for wasting compared to stunting.

Early detection must begin before birth. On average, children in low-income and middle-income settings tend to grow more slowly than the WHO global reference standard, moving further away from the global mean as they age up to 5 years. In part, this appears to be because they are born small, and children born with low birthweight or of short gestation are more likely to experience growth failure.[14] Other reviews support the importance of intervening in the pre-conception, pregnancy, or neonatal periods to prevent the burden of CGF.[14,15,32]

There are several potential mechanisms that explain how suboptimal growth is associated with an increased risk of infectious disease burden, including an altered microbiome, chronic inflammation, immune system dysregulation, changes in endothelial barrier function, and others.[37] A review of the literature concluded that although improvements in nutrition can reverse susceptibility to infection, this effect is not well characterised.[1] Reversing acute malnutrition might help make children more resilient to infection.

Our study includes meaningful updates to previously reported estimates of the CGF burden in GBD 2019.[2] We used continuous estimates of height and bodyweight by age, sex, geography, and year instead of modelled estimates of the prevalence of CGF indicators. This approach reflects the continuous nature of deviations in growth from an expected mean. We also used continuous

estimates of the relative risks of incidence and mortality due to infectious causes for each CGF indicator by age group. Together, these improvements have produced estimates of a higher specificity and with a better reflection of the true, underlying relationship between population-level exposures and risk factors.

Since GBD 2021, updated relative risk estimates have been used to quantify the burden of disease that is associated with CGF.[22] Previous iterations of GBD (eg, GBD 2017 and GBD 2019)[2] used the cause-specific mortality hazard ratios from the study by Olofin and colleagues[3] for both incidence and mortality. In addition to estimating the risk of cause-specific disease incidence, there are two main ways in which these estimates differ from those values. First, the relative risk of lower respiratory infection due to low HAZ and low WAZ are meaningfully higher than in the study by Olofin and colleagues[3] and in comparison with a separate systematic review and network meta-analysis.[22,38] Second, we identified statistically significant relationships between low HAZ and low WAZ and malaria mortality, which were not observed in the smaller sample size and discrete categorical analysis by Olofin and colleagues.[3] These CGF indicators were only included as risk factors associated with malaria mortality in GBD 2021 based on these findings and might therefore represent a gap in previous estimates of the malaria burden.

Although our updated CGF burden estimates highlight changes in the proportions of the under-5 health burden associated with wasting, stunting, and underweight compared to previous iterations of GBD, the total CGF burden remains comparable to that of GBD 2021, GBD 2019, and GBD 2017. However, even with increased relative risks and estimates of the stunting burden and after adjusting for reductions in the CGF burden in the past decade, our stunting estimates remain considerably lower than those of the Maternal and Child Nutrition Study Group (MCNS).[4] The MCNS group used CGF indicator prevalence estimated by the UN[39] and the Nutrition Impact Model Study[40] as well as cause-specific relative risks from a pooled analysis of ten longitudinal studies[3] to estimate CGF-attributable deaths in children younger than 5 years in 2011 (appendix 1 table S8). Our estimates are based on aggregating the burden associated with mild, moderate, and severe forms of each CGF indicator (eg, Z scores <–1) while the MCNS group focused only on moderate and severe forms (eg, Z scores <–2). In spite of this, our underweight and wasting burden estimates are somewhat comparable with those of the MCNS group. A comprehensive comparison between estimates would require comparing the burden using identical definitions of stunting, wasting, and underweight, which is difficult considering that it depends on exposure prevalence, risk of cause-specific death, and the total number of under-5 and cause-specific deaths. Importantly, no other group, to date, has used the updated relative risk estimates for CGF indicators used in the current study, which probably explains some of the differences in estimates.

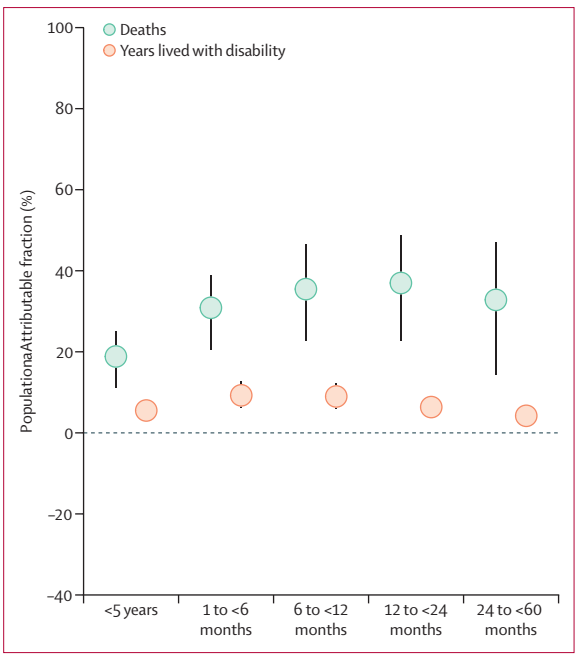


***Figure 2:*** **Percentage of all-cause deaths and years lived with disability associated with all child growth failure (mild, moderate, and severe) in children younger than 5 years, globally, in 2023**
Population attributable fraction of all-cause deaths and years lived with disability for all children younger than 5 years, as well as age-specific values (1 to <6 months, 6 to <12 months, 12 to <24 months, and 24 to<60 months) are plotted. Dots represent mean population attributable fractions and whiskers represent 95% uncertainty intervals.

There are several limitations to this analysis. First, our estimates depend on numerous sources of data for childhood growth, infectious disease incidence, and infectious disease mortality, each with various potential gaps and biases, which we attempted to resolve using expert opinion and sophisticated statistical models. One common data gap for each of the inputs into this study is that the burden of CGF is highest in countries in the lowest SDI quintiles that do not have robust vital registration and disease surveillance systems. We attempted to account for uncertainty throughout our modelling process by including measured error when possible and producing estimates incorporating uncertainty in each step. We strived to report our findings both as the mean from the posterior distributions as well as the 2·5th and 97·5th percentiles of those distributions. Capturing and reporting uncertainty is crucial in modelling burden of disease, including this report. Second, many unanswered questions remain about the impact of the COVID-19 pandemic and the associated disruptions in maternal and child health services on child nutrition and mortality.[41] We have included modelled impacts on cause-specific child mortality,[42] but strong evidence of changes in vaccine coverage or birth size and gestational age, two confounding risks for infectious disease mortality in

| | Child growth failure | Child underweight | Child wasting | Child stunting |
|---|---|---|---|---|
| **Global** | | | | |
| All causes | 880 000 (517 000 to 1 170 000) | 573 000 (236 000 to 824 000) | 428 000 (256 000 to 583 000) | 373 000 (272 000 to 477 000) |
| Diarrhoeal diseases | 243 000 (146 000 to 360 000) | 118 000 (63 600 to 195 000) | 169 000 (–11 900 to 327 000) | 84 800 (49 900 to 132 000) |
| Lower respiratory infections | 362 000 (253 000 to 465 000) | 249 000 (19 200 to 428 000) | 141 000 (88 700 to 204 000) | 196 000 (138 000 to 264 000) |
| Malaria | 107 000 (–71 300 to 341 000) | 77 400 (–44 700 to 229 000) | .. | 50 800 (–26 800 to 224 000) |
| Measles | 78 600 (30 700 to 150 000) | 40 400 (15 200 to 78 100) | 29 300 (8850 to 62 600) | 42 000 (15 000 to 80 600) |
| **Central Europe, eastern Europe, and central Asia** | | | | |
| All causes | 8790 (6390 to 11 400) | 4860 (512 to 9720) | 3420 (2670 to 4320) | 3410 (2230 to 4560) |
| Diarrhoeal diseases | 774 (380 to 1140) | 239 (123 to 386) | 568 (–21·4 to 1080) | 195 (117 to 284) |
| Lower respiratory infections | 7920 (5900 to 10 300) | 4540 (169 to 9430) | 2770 (1770 to 3830) | 3200 (2090 to 4320) |
| Malaria | 0 (0 to 0) | 0 (0 to 0) | .. | 0 (0 to 0) |
| Measles | 11·7 (5·63 to 16·4) | 3·96 (1·84 to 5·75) | 4·18 (1·55 to 8·42) | 5·76 (2·63 to 8·34) |
| **High income** | | | | |
| All causes | 623 (422 to 964) | 322 (111 to 697) | 269 (201 to 352) | 193 (138 to 264) |
| Diarrhoeal diseases | 107 (39·1 to 210) | 19·6 (9·8 to 30·3) | 78·2 (–1·7 to 202) | 20·8 (12·5 to 29·5) |
| Lower respiratory infections | 436 (299 to 718) | 222 (5·93 to 612) | 110 (63·1 to 162) | 172 (124 to 238) |
| Malaria | <0·001 (>–0·001 to <0·001) | <0·001 (>–0·001 to <0·001) | .. | <0·001 (>–0·001 to <0·001) |
| Measles | 0·0505 (0·0185 to 0·0775) | 0·0142 (0·00544 to 0·0228) | 0·0198 (0·00615 to 0·0404) | 0·0197 (0·00742 to 0·0321) |
| **Latin America and Caribbean** | | | | |
| All causes | 16 500 (12 500 to 20 800) | 10 300 (4780 to 16 000) | 6980 (5030 to 8820) | 6370 (4660 to 8200) |
| Diarrhoeal diseases | 3580 (2290 to 5100) | 1310 (730 to 2110) | 2060 (–75·7 to 4660) | 1280 (824 to 1790) |
| Lower respiratory infections | 9870 (7210 to 13 300) | 5930 (256 to 12 000) | 1890 (1090 to 2710) | 5080 (3600 to 6500) |
| Malaria | 19·2 (–9·6 to 74·3) | 13·6 (–6·94 to 46·2) | .. | 7·78 (–2·72 to 40·0) |
| Measles | 0·0394 (0·0172 to 0·0574) | 0·0123 (0·0056 to 0·0186) | 0·00933 (0·00331 to 0·0195) | 0·022 (0·00896 to 0·0325) |
| **North Africa and Middle East** | | | | |
| All causes | 30 600 (21 900 to 39 400) | 19 300 (9290 to 29 400) | 15 900 (11 400 to 20 700) | 12 600 (9160 to 16 600) |
| Diarrhoeal diseases | 6410 (3260 to 11 100) | 2780 (1340 to 5090) | 4500 (–216 to 9740) | 2240 (1150 to 3860) |
| Lower respiratory infections | 16 600 (11 400 to 23 000) | 10 600 (698 to 20 600) | 6330 (3670 to 9520) | 8440 (5490 to 11 900) |
| Malaria | 472 (–357 to 1400) | 366 (–253 to 1070) | .. | 200 (–82·7 to 827) |
| Measles | 3200 (1130 to 6630) | 1570 (568 to 3260) | 1160 (373 to 2460) | 1750 (568 to 3640) |
| **South Asia** | | | | |
| All causes | 165 000 (134 000 to 194 000) | 113 000 (49 000 to 155 000) | 98 900 (71 200 to 120 000) | 69 600 (49 700 to 91 300) |
| Diarrhoeal diseases | 44 200 (30 000 to 61 900) | 23 800 (14 900 to 36 600) | 32 600 (–2800 to 57 400) | 15 400 (9690 to 23 100) |
| Lower respiratory infections | 98 600 (77 200 to 120 000) | 70 800 (5950 to 108 000) | 49 600 (33 800 to 68 300) | 49 900 (32 100 to 68 600) |
| Malaria | 1990 (–1620 to 6700) | 1540 (–1090 to 5020) | .. | 864 (–421 to 4070) |
| Measles | 6810 (2620 to 14 300) | 3810 (1350 to 8140) | 3220 (956 to 7040) | 3450 (1250 to 7410) |
| **Southeast Asia, east Asia, and Oceania** | | | | |
| All causes | 40 400 (30 300 to 50 500) | 25 300 (10 200 to 37 400) | 19 400 (13 800 to 25 400) | 17 000 (12 400 to 22 400) |
| Diarrhoeal diseases | 10 100 (5410 to 16 800) | 4480 (2060 to 8360) | 6800 (–339 to 14 900) | 3520 (1690 to 6200) |
| Lower respiratory infections | 24 000 (16 900 to 31 500) | 16 000 (1100 to 28 900) | 8260 (4920 to 12 100) | 11 900 (7940 to 16 600) |
| Malaria | 128 (–82·9 to 477) | 90·6 (–51·0 to 317) | .. | 61·9 (–30·7 to 299) |
| Measles | 2790 (1040 to 5520) | 1350 (474 to 2790) | 926 (277 to 1950) | 1510 (562 to 3100) |
| **Sub-Saharan Africa** | | | | |
| All causes | 618 000 (299 000 to 862 000) | 399 000 (149 000 to 594 000) | 283 000 (160 000 to 412 000) | 264 000 (165 000 to 386 000) |
| Diarrhoeal diseases | 178 000 (104 000 to 274 000) | 85 100 (45 200 to 143 000) | 123 000 (–8480 to 243 000) | 62 200 (33 400 to 99 100) |
| Lower respiratory infections | 205 000 (126 000 to 288 000) | 141 000 (11 000 to 253 000) | 71 800 (41 300 to 115 000) | 117 000 (75 700 to 163 000) |
| Malaria | 105 000 (–69 000 to 333 000) | 75 400 (–43 300 to 223 000) | .. | 49 700 (–26 200 to 219 000) |
| Measles | 65 800 (25 100 to 127 000) | 33 700 (12 400 to 64 700) | 24 000 (7110 to 50 600) | 35 200 (12 200 to 69 000) |

Estimates combine burden associated with mild, moderate, and severe forms of child growth failure: stunting was defined as height-for-age Z score (HAZ) less than –1; underweight was defined as weight-for-age Z score (WAZ) less than –1; and wasting was defined as weight-for-height Z score (WHZ) less than –1, according to WHO Child Growth Standards. The results presented herein incorporate between-study variation, meaning the uncertainty intervals here represent both uncertainty in the relative risks as well as predicted variation due to between-study variation, and as such some uncertainty intervals' lower bounds fall below zero. As described in the publication associated with the method,[24] a risk factor, outcome, or cause combination would not be included in the table if the uncertainty without between-study variation was not statistically significantly different from zero. Data in parentheses are 95% uncertainty intervals. Count data are presented to three significant figures. GBD=Global Burden of Diseases, Injuries, and Risk Factors Study.

***Table 3:*** **All-cause and cause-specific deaths associated with child growth failure among children younger than 5 years at the global and GBD super-regional levels, 2023**

| | Child growth failure | Child underweight | Child wasting | Child stunting |
|---|---|---|---|---|
| **Global** | | | | |
| All causes | 18·8% (11·1 to 25·0) | 12·3% (5·1 to 17·6) | 9·2% (5·5 to 12·5) | 8·0% (6·0 to 10·3) |
| Diarrhoeal diseases | 76·7% (54·9 to 89·1) | 37·2% (24·7 to 48·4) | 53·2% (–3·1 to 86·1) | 26·8% (19·2 to 33·0) |
| Lower respiratory infections | 59·4% (48·9 to 66·8) | 40·8% (2·7 to 63·3) | 23·1% (16·0 to 29·4) | 32·1% (24·7 to 38·1) |
| Malaria | 26·4% (–17·8 to 69·5) | 19·0% (–11·3 to 48·2) | .. | 12·4% (–6·4 to 45·9) |
| Measles | 66·6% (40·0 to 76·0) | 34·2% (18·4 to 42·5) | 24·9% (10·8 to 41·0) | 35·5% (17·4 to 43·7) |
| **Central Europe, eastern Europe, and central Asia** | | | | |
| All causes | 12·4% (9·0 to 16·2) | 6·9% (0·72 to 13·8) | 4·8% (3·8 to 6·0) | 4·8% (3·2 to 6·4) |
| Diarrhoeal diseases | 61·2% (31·8 to 83·2) | 18·9% (10·3 to 27·1) | 44·8% (–1·8 to 81·1) | 15·5% (9·9 to 20·1) |
| Lower respiratory infections | 43·6% (33·0 to 57·4) | 25·0% (0·94 to 52·4) | 15·3% (10·0 to 20·5) | 17·6% (11·5 to 23·7) |
| Malaria | 0·0% (0 to 0) | 0·0% (0 to 0) | .. | 0·0% (0 to 0) |
| Measles | 40·2% (19·5 to 49·8) | 13·6% (6·4 to 18·0) | 14·4% (5·5 to 26·4) | 19·7% (9·0 to 26·4) |
| **High income** | | | | |
| All causes | 1·2% (0·82 to 1·9) | 0·6% (0·2 to 1·4) | 0·5% (0·4 to 0·7) | 0·4% (0·3 to 0·5) |
| Diarrhoeal diseases | 32·7% (12·1 to 60·1) | 6·0% (3·0 to 9·0) | 23·9% (–0·52 to 58·1) | 6·4% (3·8 to 8·4) |
| Lower respiratory infections | 34·8% (24·6 to 54·8) | 17·7% (0·5 to 47·4) | 8·8% (5·2 to 12·3) | 13·7% (10·1 to 17·9) |
| Malaria | 4·2% (–1·8 to 13·4) | 3·8% (–1·5 to 11·7) | .. | 0·5% (–0·2 to 2·0) |
| Measles | 14·2% (6·2 to 18·4) | 4·0% (1·8 to 5·4) | 5·5% (2·0 to 10·3) | 5·5% (2·4 to 7·6) |
| **Latin America and Caribbean** | | | | |
| All causes | 10·3% (7·8 to 12·9) | 6·4% (3·0 to 10·0) | 4·4% (3·1 to 5·5) | 4·0% (2·9 to 5·1) |
| Diarrhoeal diseases | 56·8% (38·6 to 75·5) | 20·7% (11·9 to 29·7) | 32·6% (–1·1 to 69·0) | 20·3% (13·7 to 26·0) |
| Lower respiratory infections | 52·4% (38·9 to 68·9) | 31·5% (1·3 to 63·4) | 10·0% (6·0 to 13·6) | 27·0% (19·0 to 33·7) |
| Malaria | 14·4% (–7·1 to 45·4) | 10·3% (–5·0 to 29·4) | .. | 5·6% (–2·4 to 24·8) |
| Measles | 27·3% (12·9 to 34·5) | 8·5% (4·0 to 11·2) | 6·5% (2·5 to 12·3) | 15·3% (6·9 to 21·6) |
| **North Africa and Middle East** | | | | |
| All causes | 10·9% (7·9 to 13·8) | 6·9% (3·3 to 10·3) | 5·7% (4·0 to 7·4) | 4·5% (3·3 to 5·9) |
| Diarrhoeal diseases | 68·4% (43·9 to 83·7) | 29·6% (19·1 to 40·0) | 47·8% (–2·1 to 81·2) | 23·9% (16·4 to 29·7) |
| Lower respiratory infections | 54·3% (44·1 to 63·4) | 34·7% (2·0 to 58·9) | 20·8% (13·9 to 27·1) | 27·7% (19·2 to 35·0) |
| Malaria | 31·3% (–22·7 to 78·3) | 24·3% (–16·2 to 58·1) | .. | 13·1% (–6·7 to 50·9) |
| Measles | 61·4% (34·5 to 71·2) | 30·0% (15·2 to 38·3) | 22·4% (9·3 to 38·9) | 33·5% (15·6 to 41·5) |
| **South Asia** | | | | |
| All causes | 14·6% (11·8 to 16·8) | 10·0% (4·3 to 13·2) | 8·7% (6·3 to 10·4) | 6·1% (4·4 to 7·9) |
| Diarrhoeal diseases | 79·4% (58·3 to 88·3) | 42·8% (29·6 to 54·0) | 58·6% (–3·9 to 86·6) | 27·7% (19·6 to 34·2) |
| Lower respiratory infections | 53·4% (45·4 to 59·0) | 38·4% (2·9 to 56·2) | 26·9% (19·5 to 33·4) | 27·0% (17·4 to 34·0) |
| Malaria | 32·1% (–24·3 to 78·9) | 25·0% (–17·4 to 60·1) | .. | 13·8% (–7·3 to 51·8) |
| Measles | 75·9% (49·1 to 85·7) | 42·5% (23·9 to 51·6) | 36·0% (16·5 to 55·4) | 38·4% (19·2 to 46·8) |
| **Southeast Asia, east Asia, and Oceania** | | | | |
| All causes | 12·3% (9·1 to 15·2) | 7·7% (3·1 to 11·2) | 5·9% (4·1 to 7·7) | 5·2% (3·8 to 6·8) |
| Diarrhoeal diseases | 73·0% (50·6 to 86·9) | 32·5% (20·3 to 43·5) | 49·1% (–2·2 to 84·1) | 25·5% (17·3 to 31·7) |
| Lower respiratory infections | 56·8% (43·9 to 66·3) | 38·0% (2·2 to 62·9) | 19·6% (13·0 to 25·3) | 28·2% (19·6 to 35·1) |
| Malaria | 25·7% (–17·2 to 68·9) | 18·1% (–10·6 to 47·0) | .. | 12·3% (–6·1 to 46·3) |
| Measles | 61·5% (35·8 to 70·9) | 29·7% (15·8 to 37·2) | 20·6% (8·6 to 35·3) | 33·3% (16·4 to 41·2) |

(Table 4 continues on next page)

children, could change our understanding of the current and forecasted burden of CGF. Third, although we believe that our analysis strengthens previous burden estimates by using estimated continuous distributions for CGF prevalence and for the risk of infections associated with CGF, our approach is cross-sectional in time and might not reflect the longitudinal nature of childhood growth. For example, a child who has been experiencing growth failure for several months might have a different risk of infection or death than a child with a newly incident case of growth failure—a nuance that is not captured in our analysis. Such an analysis would need to account for repeated measurements of growth and potentially repeated measures of infection events.[43] It is likely that a cross-sectional measurement of growth does not accurately represent an individual child's risk of disease, especially given the importance of birth and early-life exposures.[35] Fourth, as mentioned earlier, low birthweight and short

| | Child growth failure | Child underweight | Child wasting | Child stunting |
|---|---|---|---|---|
| (Continued from previous page) | | | | |
| **Sub-Saharan Africa** | | | | |
| All causes | 23·4% (11·3 to 32·8) | 15·1% (5·6 to 22·3) | 10·7% (6·1 to 15·6) | 10·0% (6·3 to 14·6) |
| Diarrhoeal diseases | 77·3% (55·2 to 90·2) | 37·0% (24·5 to 48·6) | 53·1% (–3·0 to 87·0) | 27·0% (19·4 to 33·3) |
| Lower respiratory infections | 65·2% (52·5 to 73·9) | 44·7% (2·9 to 69·7) | 22·9% (15·1 to 30·1) | 37·2% (30·6 to 43·2) |
| Malaria | 26·3% (–17·7 to 69·4) | 18·9% (–11·2 to 48·0) | .. | 12·4% (–6·3 to 45·8) |
| Measles | 66·2% (39·5 to 75·8) | 33·9% (18·1 to 42·2) | 24·3% (10·4 to 40·2) | 35·4% (17·4 to 43·7) |

Estimates combine burden associated with mild, moderate, and severe forms of child growth failure: stunting was defined as height-for-age Z score (HAZ) less than –1; underweight was defined as weight-for-age Z score (WAZ) less than –1; and wasting was defined as weight-for-height Z score (WHZ) less than –1, according to WHO Child Growth Standards. The results presented herein incorporate between-study variation, meaning the uncertainty intervals here represent both uncertainty in the relative risks as well as predicted variation due to between-study variation, and as such some uncertainty intervals' lower bounds fall below zero. As described in the publication associated with the method,[24] a risk factor, outcome, or cause combination would not be included in the table if the uncertainty without between-study variation was not statistically significantly different from zero. Data in parentheses are 95% uncertainty intervals. Population attributable fractions are presented to one decimal place. GBD=Global Burden of Diseases, Injuries, and Risk Factors Study.

***Table 4:*** **All-cause and cause-specific population attributable fraction of deaths among children younger than 5 years for child growth failure at the global and GBD super-regional levels, 2023**

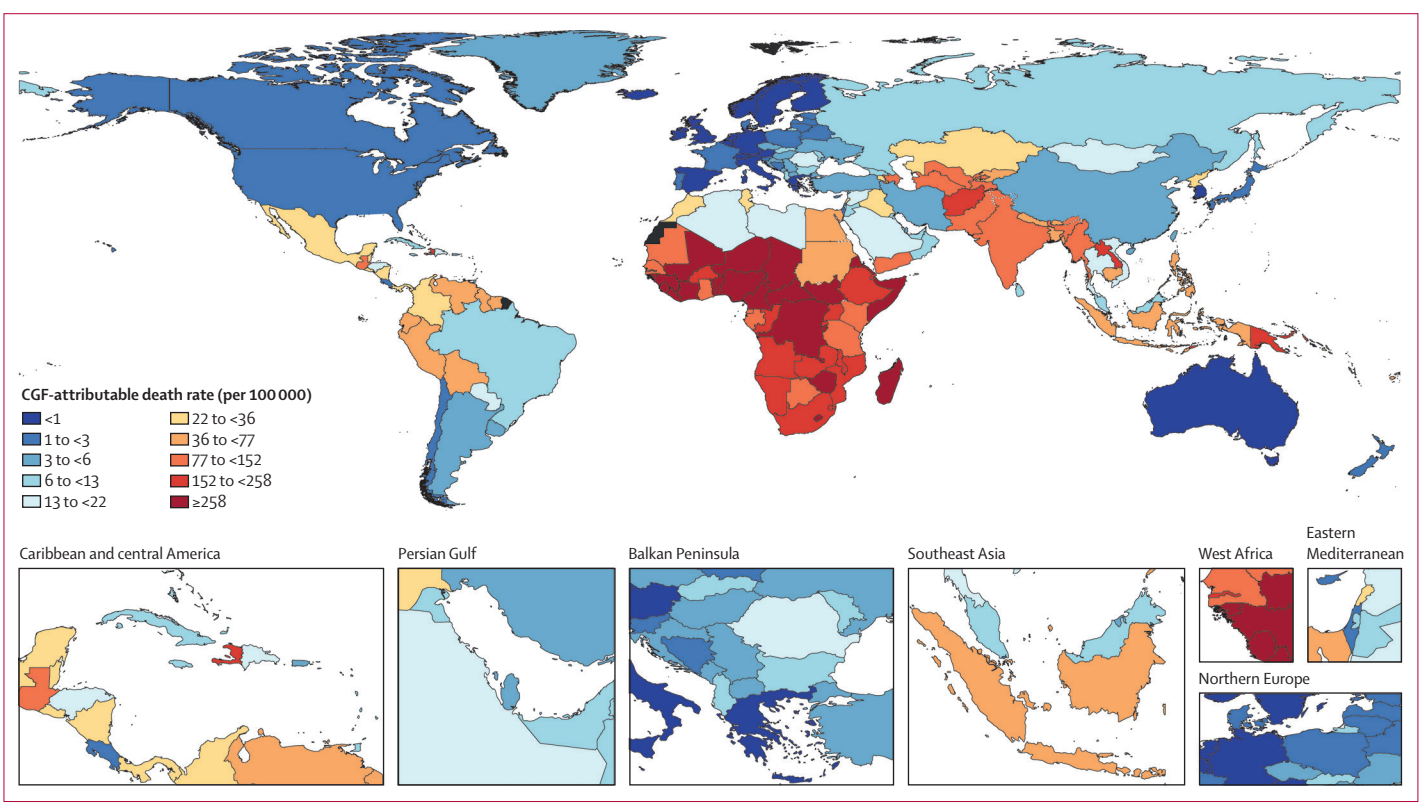


***Figure 3:*** **Deaths from all child growth failure (mild, moderate, and severe) in children younger than 5 years per 100 000 in 2023**
CGF=child growth failure.

gestation have been found to be correlated with CGF outcomes at birth, during the critical first 1000 days of life, and throughout childhood. Better data and a deeper analysis are needed to carefully link health status at and before birth to health outcomes throughout childhood to parse the relative risks of wasting, stunting, and underweight from low birthweight and short gestation. Finally, we used an adjustment after modelling our relative risk curves to account for the correlation between different growth failure indicators. For example, children who have a low height-for-age are more likely to have low weight-for-age.[12] Future work to simultaneously quantify such correlations in a single statistical model might have an important impact on risk estimates.

The global burden of disease associated with all CGF (mild, moderate, and severe) is substantial and

concentrated in south Asia and sub-Saharan Africa. Children experiencing growth failure are at increased risk of mortality and incidence of infectious diseases. Although the burden associated with CGF has decreased in the past 20 years, more must be done to prevent children from being born small or preterm and to prevent children's growth from faltering. All children deserve an opportunity to have a healthy and productive life, but too many are being denied that chance because of poor growth. By accurately parsing the relative associations of the three main CGF indicators with childhood mortality and morbidity, our estimates provide an unprecedented opportunity to target interventions specifically for the dominant indicator, outcome, and cause of burden in each location.

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See Online for appendix 2

Please see appendix 2 (pp 4–16) for the affiliations for individual authors.

**Contributors**

Please see appendix 2 (pp 17–24) for more detailed information about individual author contributions to the research, divided into the following categories: managing the overall research enterprise; writing the first draft of the manuscript; primary responsibility for applying analytical methods to produce estimates; primary responsibility for seeking, cataloguing, extracting, or cleaning data; designing or coding figures and tables; providing data or critical feedback on data sources; developing methods or computational machinery; providing critical feedback on methods or results; drafting the manuscript or revising it critically for important intellectual content; and managing the estimation or publications process. The lead and senior authors had full access to the data in the study and final responsibility for the decision to submit the manuscript for publication.

**Declaration of interests**

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### Data sharing

To download the citations and metadata for the input data used in these analyses, please visit the Global Health Data Exchange GBD 2023 Sources Tool: https://ghdx.healthdata.org/gbd-2023/sources. To download estimates produced in these analyses, please visit the GBD Results Tool: https://vizhub.healthdata.org/gbd-results/.

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